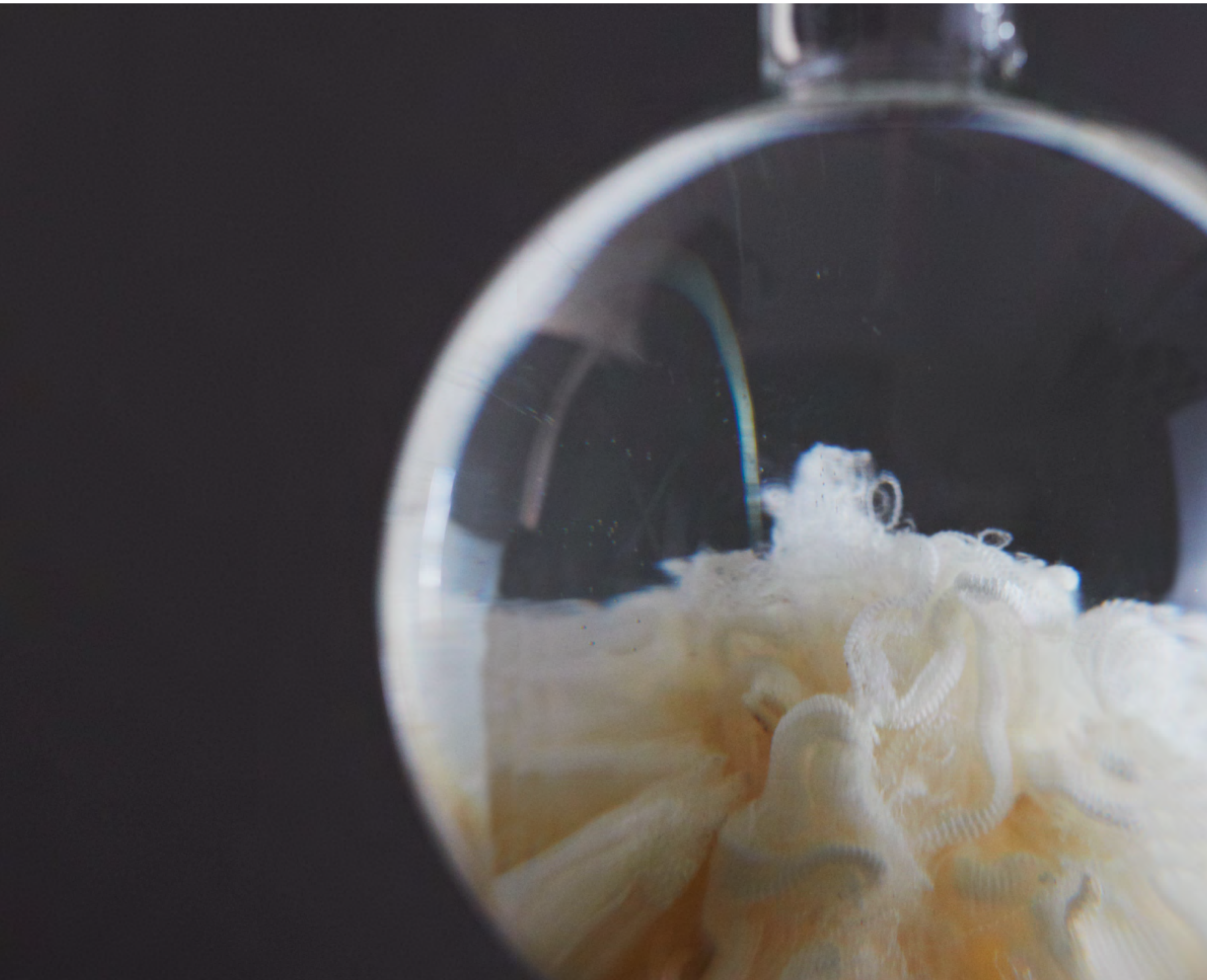
THE WOOLMARK COMPANY

WOOL SCIENCE, TECHNOLOGY AND DESIGN EDUCATION PROGRAM

FACILITATOR GUIDE

WOOL FIBRE SCIENCE



CONTENTS

THE WOOLMARK COMPANY | AUSTRALIAN WOOL INNOVATION

The Woolmark Company (TWC) is a subsidiary of Australian Wool Innovation (AWI) and is the global authority on Merino wool. With a network that spans the entire global wool supply chain, The Woolmark Company builds awareness and promotes the unique traits of nature's finest fibre.

Australian Wool Innovation is the research, development and marketing body for the Australian wool industry. More than 60,000 Australian woolgrowers co-invest with the Australian government to support the activities carried out by AWI and TWC along the global wool supply chain.

The Woolmark Company supports and connects global supply chain participants through initiatives such as The Wool Lab and Wool Lab Sport. These internationally renowned wool-sourcing tools provide designers, retailers and brands with the latest trends in wool yarns, fabrics and technologies, while promoting Australian Merino wool as the ultimate fibre of choice for apparel.

Marketing activities focus on education and awareness raising to ensure consumers, manufacturers and designers are aware of Australian wool's benefits and qualities, can capitalise on wool's inherent properties, and can successfully integrate wool into their product lines.

THE WOOLMARK WOOL SCIENCE, TECHNOLOGY AND DESIGN EDUCATION PROGRAM OVERVIEW

The Woolmark Wool Science, Technology and Design Education Program combines a series of introductory and advanced courses of study developed to meet the needs of tertiary-level participants studying within the fields of: textile science and engineering, fashion and textile design and/or textile manufacturing. Individual courses within the series may also be of interest to participants studying sheep and wool science, and those working in the wool production, raw wool processing, textile manufacturing and textile sales and marketing industries.

Introductory level courses are suitable for participants studying at first or second-year tertiary levels, while the advanced courses are aimed at participants in their more senior years of study. The extension courses can be used for specific course requirements.

INTRODUCTORY COURSES

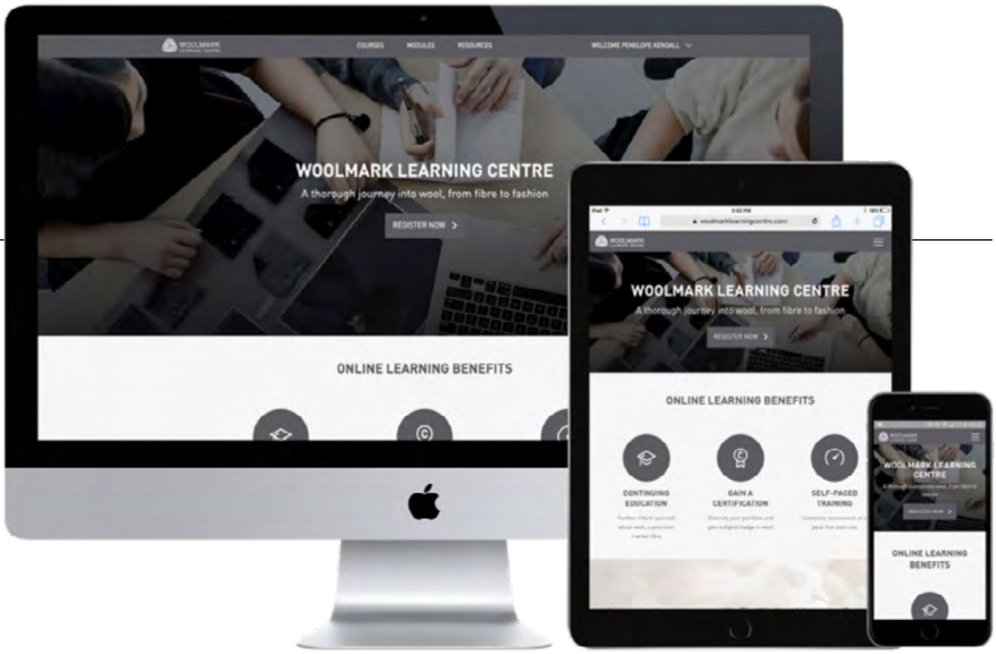
- **Wool fibre science**
- Introduction to wool processing

ADVANCED COURSES

- Raw wool scouring
- Worsted top-making
- Worsted and woollen spinning
- The dyeing of wool
- Wool fabric finishing

EXTENSION COURSES (IN DEVELOPMENT)

- Finishing of wool knitwear
- Wastewater management
- Wool product quality
- Methods of wool fabric formation



THE WOOLMARK LEARNING CENTRE

The *Woolmark Learning Centre* is a freely accessible, online learning platform, which supports The Woolmark Company's commitment to education and awareness raising with regard to wool, wool processing and product innovation.

Make sure you have completed the *Wool Appreciation Course* online before delivering any courses of the *Wool Science, Technology and Design Education Program* to familiarise yourself with The Woolmark Company's approach and core messages about wool production and the wool supply chain.

It is also important to encourage all participants to explore the online *Woolmark Learning Centre* to reinforce and build on the knowledge they have gained by attending this introductory course.

The W*oolmark Learning Centre* can be accessed at:
https://www.woolmarklearningcentre.com/

INTRODUCTION TO THIS FACILITATOR GUIDE

This Facilitator Guide covers the *Wool fibre science* course of the *Wool Science, Technology and Design Education Program*.

The information in this Guide will support you to:

- deliver the technical content across a series of face-to-face lectures in an engaging and easy-to-follow way
- carry out a range of practical demonstrations and interactive discussions to support participant learning.

This Facilitator Guide provides:

- an overview of the *Wool Science, Technology and Design Education Program* courses
- the target audience for the *Wool fibre science course*
- the prerequisites for the course
- an overview and learning objectives for *Wool fibre science*
- a suggested agenda for delivering *Wool fibre science*
- an overview and the learning objectives for each module within *Wool fibre science*
- course materials and resources required to deliver *Wool fibre science*
- administrative requirements and institutional responsibilities when delivering *Wool fibre science*
- guidelines and processes regarding participant recognition upon completing *Wool fibre science*
- links to participant and facilitator feedback and evaluation questionnaires
- a facilitator checklist to enable successful planning and preparation leading up to, during and following delivery
- recommended room layout for small venues or groups
- a guideline for the effective and engaging delivery of the course content.

INTRODUCTION TO THIS COURSE

Wool fibre science is an introductory-level course, which provides participants with a foundational understanding of wool, its structural, physical and chemical characteristics and ensuing product benefits. This will underpin the content covered in subsequent courses of the program.

The course structure and module plan contained in this Facilitator Guide indicate the technical content to be addressed, however it's important to adapt the focus of your training in line with participants' existing understanding and specific target audience requirements.

TARGET AUDIENCE

The *Wool fibre science* course is primarily aimed at tertiary-level participants studying within the fields of: textile science and engineering, fashion and textile design, textile manufacturing. It may also be of interest to participants studying sheep and wool science, and those working in the wool production, raw wool processing, textile manufacturing and textile sales and marketing industries.

The course is designed to be delivered face to face, in groups of 6 – 50 people, although the ideal number of participants who can attend course lectures depends on the resources available to support the delivery.

COURSE PREREQUISITES

As an introductory course, *Wool fibre science* is suitable for participants with little or no former knowledge of wool or the wool industry.

If this is the first *Wool Science, Technology and Education Design Program* being delivered to these participants, start the initial lecture with an *Introduction to The Woolmark Company*.

This presentation is included in the *Wool fibre science* facilitator slides as an optional introductory module.

COURSE LEARNING OBJECTIVES

By the end of the *Wool fibre science* course, participants are expected to be able to:

- differentiate the properties of wool from other fibres
- learn about the structure of the wool fibre and the complex components that make up its structure
- understand the physics of the fibre and the relationship between the physical properties and the fibre structure and chemistry
- discover the complex chemistry of the wool fibre and its impact on the behaviour of the fibre during processing and wear
- describe the benefits of wool in terms of comfort, ease of wear, safety, appearance and versatility.

COURSE AGENDA

Wool fibre science consists of seven one-hour lectures, each supported by a set of PowerPoint slides, videos and recommended demonstrations, as outlined in the table below.

MODULE | SLIDE NUMBER	VIDEOS AND PRACTICAL DEMONSTRATIONS
Module 1: Wool and other animal fibres | 23 slides	Slide 11: What is wool (video) Slide 12: Greasy wool (handout) Slide 14: Animal fibre comparison (handout) Slide 16: Australian sheep farm (video) Slide 22: Fine vs broad wool (handout)
Module 2: The structure of wool fibres | 29 slides	Slide 2: Structure of the wool fibre (video) Slide 3: Structure of the wool fibre (3-D model) Slide 6: Fibre friction (demonstration) Slide 10: Wetting out (demonstration) Slide 20: Impact on crimp (handout)
Module 3: The physics of the wool fibre | 27 slides	Slide 5: Glass transition (demonstration) Slide 14: Prickle factor (demonstration) Slide 16: Fibre diameter and 'stiffness' (demonstration) Slide 16: Fibre moisture and 'stiffness' (demonstration) Slide 17: Recovery and creep (demonstration) Slide 23: Wrinkle recovery (demonstration) Slide 25: Static electricity (demonstration)
Module 4: The chemistry of the wool fibre | 31 slides	Slide 12: Disulphide crosslinks (demonstration) Slide 14: Ionic crosslinks (demonstration) Slide 26: The chemistry of yellowing (handout)
Module 5: The setting of the wool fibre | 17 slides	Slide 2: Cohesive set (demonstration introduction) Slide 3: Deformation and set (demonstration) Slide 4: Types of set (demonstration) Slide 7: Cohesive set (demonstration conclusion) Slide 12: Siroset (video)
Module 6: The shrinkage of wool products | 28 slides	Slide 4: Relaxation shrinkage (demonstration) Slide 11: Freedom of movement (demonstration) Slide 21: Felt-resist processing of wool top (video)
Module 7: The benefits of wool | 25 slides	Slide 3: Wool runs on grass (video) Slide 7: Comfort (handout) Slide 8: Comfort (demonstration) Slide 9: Moisture management (demonstration) Slide 18: Flammability of wool (video) Slide 21: Wrinkle recovery (demonstration)

MODULE OVERVIEW AND LEARNING OBJECTIVES

Module 1 — Wool and other animal fibres starts off this seven-module course by exploring the source of wool (sheep) and a range of other natural fibres, the impact of sheep breed on wool type and value and compares the basic attributes of wool with a range of other natural and synthetic fibres. A brief overview of global wool production and the factors that contribute to the value of wool conclude this introduction to wool.

By the end of this module participants are expected to be able to:

- describe wool in the context of other natural and synthetic fibres and differentiate wool from other animal hair
- recognise the differences between fibres grown by sheep and those grown by other animals
- nominate the major sheep-growing countries in the world
- recognise there are different types of sheep grown for different purposes and the differences between the types of wool produced by different types of sheep
- describe the key features of wool grown by Merino sheep
- nominate the features of wool that impact on its value.

Module 2 — The structure of wool fibres introduces participants to the structural components that make up the wool fibre and takes a layer-by-layer look at each component and its impact on the wool processing pipeline and end product attributes.

By the end of this module participants are expected to be able to:

- name the major features of the wool fibre
- describe the various layers of the cuticle cells and their characteristics
- describe the types of cortical cells and their characteristics
- describe the impact of the distribution of the cortical cells
- describe, in general terms, the components of the cortical cells
- describe the cell membrane complex and its role
- describe the brick, mortar and tile model of wool.

Module 3 — The physics of the wool fibre helps participants become familiar with the concepts of moisture sorption, glass transition and melting point of wool and other fibres. The four key physical properties of the wool fibre (fibre diameter, tensile properties, bending properties and frictional properties) complete this module.

By the end of this module participants are expected to be able to:

- list the five key physical properties of wool fibre (namely diameter, tensile and bending properties, friction and static generation)
- describe the attributes of these physical properties
- explain the impact the glass transition temperature has on the physical properties of the wool fibre and the variables that affect it.
- explain the concept of ageing and the impact ageing has on the physical properties of the wool fibre and the variables that affect it.
- explain the implications of the wool fibre's physical properties on fibre performance.

Module 4 — The chemistry of the wool fibre covers the chemical composition of the wool fibre. The module provides an overview of the proteins and lipids that form wool and the various crosslinks that exist between protein macromolecules. The concept of disulphide interchange and its role in the setting processes in wool is introduced along with the bonding of the surface lipid to wool and its implications for wool 'felt-resist' treatment and the causes of yellowing of wool.

By the end of this module participants are expected to be able to:

- nominate the chemical components of wool fibre
- describe the four major categories of crosslinking that occur between protein chains within wool fibre and the relevance each to processing
- outline the effects of pH on fibre properties
- describe some of the causes of wool yellowing and its relevance to processing.

Module 5 — The setting of the wool fibre familiarises participants with the concepts of set and setting, and explains when setting occurs during the manufacturing processes and during wear. The three key types of setting (i.e. cohesive, temporary and permanent setting) and the differences between each of them are covered. The mechanisms of setting, in terms of the physics and chemistry of wool are outlined, as are some of the processes used to set wool.

By the end of this module participants are expected to be able to:

- describe three types of wool setting (i.e. cohesive, temporary and permanent) and the conditions required for each to be successfully achieved
- describe the mechanism of each type of wool set, in terms of glass transition behaviour and fibre crosslinking
- describe methods for increasing the rate of setting
- describe methods for reducing the rate of setting.

Module 6 — The shrinkage of wool products explains the difference between relaxation shrinkage and felting shrinkage and the causes and mechanisms that drive both processes. The key 'felt-resist' treatments used to prevent felting shrinkage and impact machine washability to wool products is also explored in this module.

By the end of this module participants are expected to be able to:

- distinguish between the two different types of dimensional change (i.e. relaxation shrinkage and felting shrinkage)
- describe the consequences of each type of shrinkage
- explain the five factors that contribute to the felting shrinkage of wool
- describe the management of each type of shrinkage
- describe methods of treating wool to prevent felting shrinkage and the mechanisms involved.

Module 7 — The benefits of wool is the final module in the course and ties together the concepts of the previous six modules, revealing how the structure, physics and chemistry of the wool fibre translate into a range properties and benefits, which deliver sound reasons for choosing wool for a wide variety of applications.

By the end of this module participants are expected to be able to:

- describe the key properties and benefits of wool as a fibre
- relate these properties to the fibre's structure, physics and chemistry
- explain why consumers would benefit from choosing wool for a range of applications.

COURSE MATERIALS AND RESOURCES

To deliver the *Wool fibre science* series of lectures, you will need the following materials:

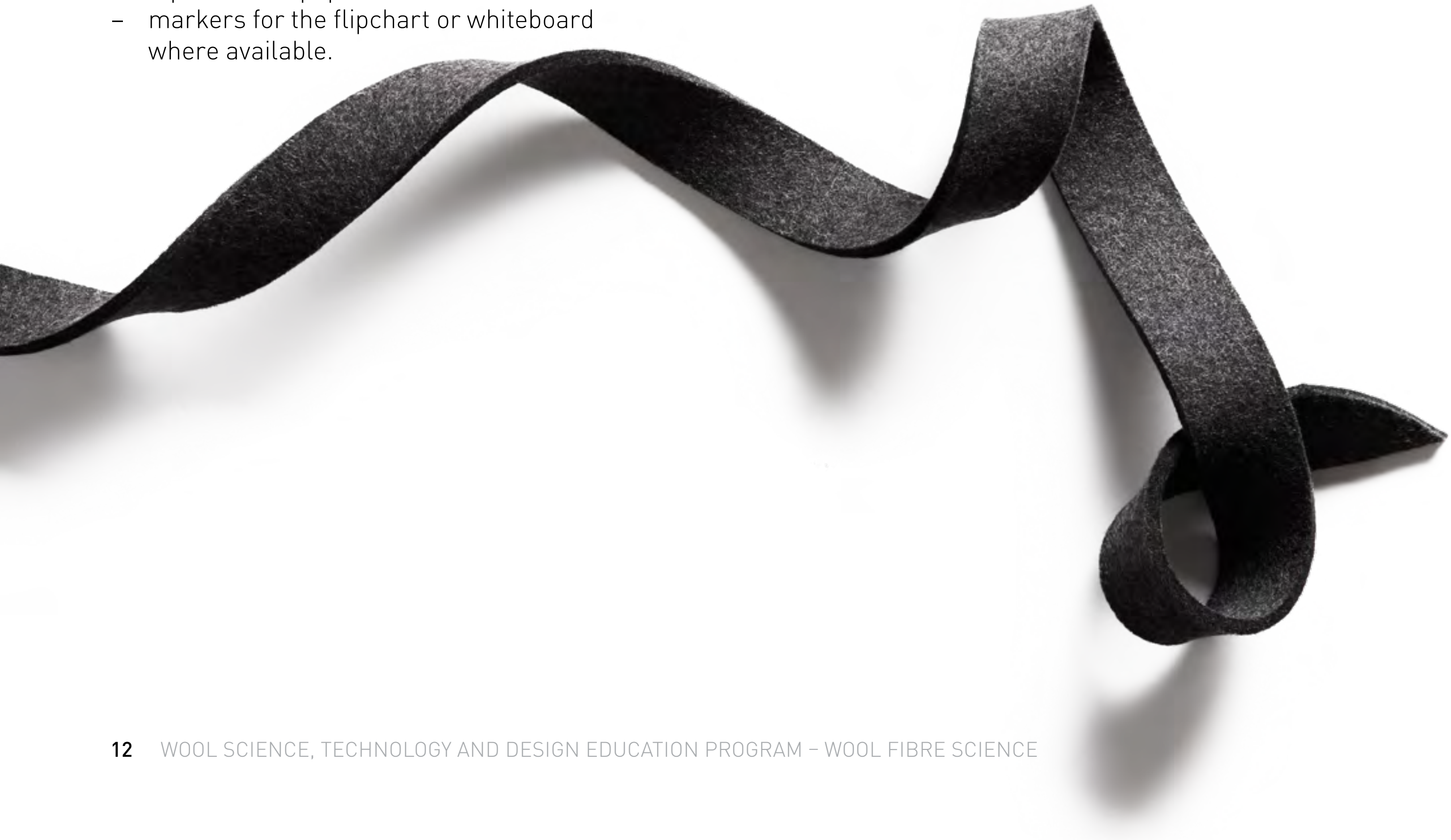
Provided in each course Facilitator Pack:

- Facilitator Guide (PDF provided via DropBox link)
- facilitator slides (PowerPoint files for each module provided via DropBox link)
- participant sign-on sheet (Word template provided via DropBox link)
- Participant Guide (PDF provided via DropBox link)
- Demonstration kit (see details below)
- Certificates of Participation (supplied by the regional Woolmark Company office on confirmation of participant numbers).

To be sourced by facilitators:

- speakers (for listening to the videos)
- laptop, data projector and overhead screen
- participant name tags (e.g. sticky labels or equivalent and a black marker to write participant names)
- flipchart and paper or access to a whiteboard
- markers for the flipchart or whiteboard where available.

NOTE: The WST&DEP materials are designed to delivered on a Microsoft 365 platform, on a 64bit hard drive. Please contact the regional Woolmark office if you do not have access to adequate technology.



WOOL FIBRE SCIENCE DEMONSTRATION KIT

A range of practical demonstrations, group activities, handouts and samples is recommended to be used throughout this course to support participant learning and complement the content delivered in the lectures.

Recommended resources are listed at the start of each module in *Wool fibre science* Facilitator Guide.

The following samples and resources for demonstrations are provided in the *Wool fibre science* Demonstration kit (resources not supplied in the kit will need to be supplied by the facilitator):

Module 1:
- wool computer bag
- fine wool sample
- broad wool sample
- camel hair sample
- alpaca fibre sample
- cashmere sample
- greasy wool sample

Module 2:
- 3-D model of the wool fibre
- delipidised wool fabric
- untreated wool fabric

Module 3:
- coarse 'prickly' fabric
- fine 'soft' fabric

Module 4:
- plasma-treated fabric
- untreated fabric
- yellowed wool fabric
- untreated (normal) wool fabric

Module 5:
- wool fabric
- conditioned wool fabric
- dry wool fabric
- wool fabric set in pressure decatiser
- wool fabric pressed with an iron

Module 6:
- knitted fabric
- felted and unfelted sock
- tightly woven fabric (e.g. suiting fabric)
- loosely knitted fabric (e.g. sweater)
- felted (non-woven) fabric

Module 7:
- TWC knitting needles (fine and large).

ADMINISTRATIVE DETAILS

ORGANISATIONAL RESPONSIBILITIES

Institutions delivering the *Wool Science, Technology and Design Education Program* course Wool fibre science will be responsible for:

- ensuring all facilitators have completed the *online Wool Appreciation Course* prior to delivering their first course
- providing the venue and equipment required to support the program (i.e. lecture theatre, data projector, data screen, flip chart, whiteboard and markers)
- enrolling the participants in the course
- administrative paperwork (i.e. participant sign-in sheets, name tags etc.)
- providing administrative support for communication between the facilitator and the participants
- ensuring both the participants and the facilitator have the required access to external sites required to support participant learning
- providing supporting services, as required. (e.g. interpreter, transport to or from external sites)
- providing The Woolmark Company with participant numbers, and participant and facilitator feedback and course evaluation post delivery.

The Woolmark Company will be responsible for providing:

- Facilitator Guide (PDF provided via DropBox link)
- Facilitator slides (PowerPoint files for each module provided via DropBox link)
- participant sign-on sheet (Word template provided via DropBox link)
- Participant Guide (PDF provided via DropBox link)
- Demonstration kit
- Certificates of Participation (printed copies will be provided by the local TWC office upon request).

NOTE: Course materials are provided in English. If translation to the local language is required, please contact your regional Woolmark Company office.

PARTICIPANT RECOGNITION

At the conclusion of the seven *Wool fibre science* lectures, each participant who has attended all lectures is eligible to receive a Woolmark Company-endorsed Certificate of Participation.

PROGRAM EVALUATION

Feedback from those attending the *Wool fibre science* course must be collected by way of an online survey link. This feedback will be used to adapt the course on an annual basis, if and where necessary, to ensure it achieves the desired objectives in the most effective way.

Feedback from those delivering the *Wool fibre science course* also must be submitted at the completion of the course.

Facilitator survey:
www.woolmarklearningcentre.com/wstd-surveyfacilitator

Participant survey:
www.woolmarklearningcentre.com/wstd-surveyparticipant

FACILITATOR CHECKLIST

The following list outlines the actions required before, during and after delivery the *Wool fibre science* course.

One month before:

- ☐ Fully familiarise yourself with the course materials.
- ☐ Check you have all the materials required to deliver the course (including the facilitator materials and the wool demonstration kit).
- ☐ If you are an external facilitator, obtain contact details for your key point of contact at the host institution. Make contact, introduce yourself and arrange regular meetings leading up to the delivery dates.
- ☐ Confirm the number of participants attending, along with the year level and any previous studies relevant to the course.
- ☐ Confirm any specific needs for the target audience in consultation with the institution.
- ☐ Familiarise yourself with the venue and facilities that will be available for the lectures including room size and potential room layout options (see notes on the following page regarding room layout). This may be via site maps or discussions with your key contact.
- ☐ Confirm equipment available at the venue (e.g. data projector, screen, speakers, laboratory equipment).
- ☐ Adapt the program (if required) to meet the needs of the participants and venue facilities.
- ☐ Check the availability of participant materials in sufficient quantity.
- ☐ Ensure you have reviewed the delivery material and have checked any videos for the upcoming lectures will work on the available equipment.

One week before:

- ☐ Confirm shipping details of the course materials and equipment (if required).
- ☐ Confirm transport between the institution and any external site visits (if required).
- ☐ Confirm names of the participants attending the course.
- ☐ Ensure you have ordered a sufficient number of the 'Certificates of Participation' to be distributed to the appropriate participants following the completion of the final lecture.
- ☐ Ensure your wardrobe contains various wool garments. In order to demonstrate the benefits and versatility of wool and wool products, facilitators are encouraged to wear as much wool as possible, across a range of garment types. For example:
  - wool trousers or skirt
  - wool t-shirt or undershirt, long-sleeved shirt, sweater or jacket
  - wool socks.

One day before:

- ☐ Arrange to meet your key institution contacts face to face and any key contacts at external sites (if required).
- ☐ Familiarise yourself with the venue's emergency procedures.
- ☐ Tour the facility. Visit the rooms you will be using.
- ☐ Check the equipment you need is available in working order and you know how to use it (including lighting, heating and cooling).
- ☐ Ensure you have checked any videos for the upcoming lectures will work on the available equipment, including audio equipment (e.g. speakers). Familiarise yourself with the rest rooms available at the venue.
- ☐ Take note of any challenges associated with each room (e.g. noise, heat, lighting). Identify strategies to minimise these challenges.
- ☐ Prepare the participants materials you will need to distribute at the first lecture (e.g. participant name tags and sign-in sheets).
- ☐ Check you have all the materials you need to deliver the course (including the Participant Guides).
- ☐ Distribute the PDF (soft copy) of the Participant Guide to participants prior to the first lecture if possible, to allow them to become familiar with the course materials and content.

Prior to each lecture:

- ☐ Ensure you are wearing a variety of wool garments that reflect the benefits and versatility of wool and wool products
- ☐ Arrive 30 minutes before each lecture to check the equipment is available and working.

At commencement of the first lecture:

- ☐ Distribute the hard copy of the Participant Guide to each participant.
- ☐ Distribute name tags to each participant.
- ☐ Record those who are present

After each lecture:

- ☐ Stay to answer any questions the participants may have about the course content.

Prior to the final lecture:

- ☐ Ensure you have received a sufficient number of the 'Certificates of Participation' to be distributed to the appropriate participants following the completion of the final lecture.

At the completion of the course:

- ☐ Provide participants with the online feedback and evaluation survey link.
- ☐ Complete and submit your own online evaluation survey.
- ☐ Provide feedback to the institution regarding the successful completion of the course.
- ☐ Explore future delivery opportunities and liaise with The Woolmark Company regional office.

Post-course survey links:

Facilitator survey:
www.woolmarklearningcentre.com/wstd-surveyfacilitator

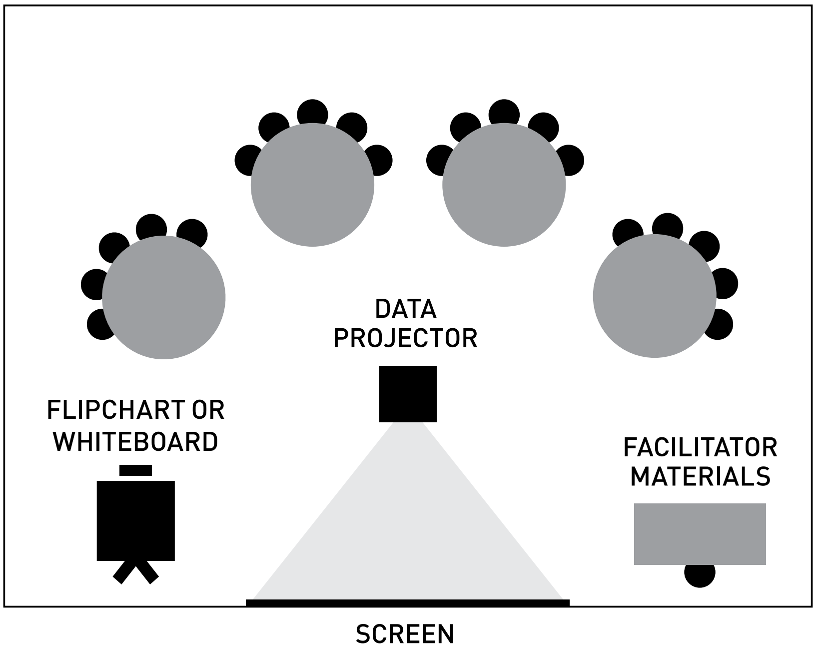
Participant survey:
www.woolmarklearningcentre.com/wstd-surveyparticipant

ROOM LAYOUT

The *Wool fibre science* course is designed to be delivered face-to-face, in groups of 6 – 50 people. In many cases this will mean delivery occurs in a large lecture theatre and there will not be an opportunity to influence the physical learning environment.

In smaller groups and settings where the learning environment can be influenced:

- arrange tables in a cabaret style (see diagram below) facing a flipchart or whiteboard and a data projector/screen
- allow for small group discussion in groups of three or four.



A GUIDELINE FOR THE EFFECTIVE AND ENGAGING DELIVERY OF THE COURSE CONTENT.

The course materials are designed to achieve a Gunning Fog Index of 8–10, with the exclusion of technical terms specific to the course.

The Gunning Fog Index formula implies short sentences written in plain English achieve a better score than long sentences written in complicated language.

Materials with a Gunning Fog Index of 8 have a readability equivalent to a Grade 8 reading level for English speaking participants. It is considered the ideal score for readability. Anything above 12 is too hard for most people to read[1].

Information is provided in Appendix A for facilitators who wish to enhance their skills in facilitation by acknowledging the different learning styles of participants.

Research has shown each person has a preferred way of learning[2]. As adults, we tend to adopt the learning style with which we are most comfortable and ignore learning styles with which we are unfamiliar or uncomfortable. This means learning is most effective when a participant can process information and solve problems in a way that meets their preferred learning style.

When you know a person's learning style, you can present information to them so they can grasp it quickly and easily. If information is presented in a way that is at odds with their preferred learning style, the participant will find it more difficult to learn. Sometimes this means, as a facilitator, you may have to present information to a participant in a way that will engage them, although that may not be your preferred method. If you do not accommodate the participant's preferred learning style, you make it harder to get the message across, which may lead to frustration on your part, as well as a lack of commitment from the participant.

Honey & Mumford have developed a questionnaire, included in Appendix A, which helps you identify your participants' preferred learning styles.

For those who are interested, you could provide this questionnaire to your participants one month out from delivery. Using the results from this survey you can cater to your participants' preferred learning styles more effectively.

1 http://www.usingenglish.com/glossary/fog-index.html, http://juicystudio.com/services/readability.php
2 Kolb D. A. (1984). Experiential Learning experience as a source of learning and development, New Jersey: Prentice Hall.

APPENDIX A: LEARNING STYLES QUESTIONNAIRE

NAME: ___________________________

This questionnaire is designed to find out your preferred learning style(s). Over the years you have probably developed learning "habits" that help you benefit more from some experiences than from others. Since you are probably unaware of this, this questionnaire will help you pinpoint your learning preferences so that you are in a better position to select learning experiences that suit your style and having a greater understanding of those that suit the style of others.

This is an internationally proven tool designed by Peter Honey and Alan Mumford.

There is no time limit to this questionnaire. It will probably take you 10-15 minutes. The accuracy of the results depends on how honest you can be. There are no right or wrong answers.

If you agree more than you disagree with a statement put a tick by it.

If you disagree more than you agree put a cross by it.

Be sure to mark each item with either a tick or cross.

- ☐ 1. I have strong beliefs about what is right and wrong, good and bad
- ☐ 2. I often act without considering the possible consequences
- ☐ 3. I tend to solve problems using a step-by-step approach
- ☐ 4. I believe that formal procedures and policies restrict people
- ☐ 5. I have a reputation for saying what I think, simply and directly
- ☐ 6. I often find that actions based on feelings are as sound as those based on careful thought and analysis
- ☐ 7. I like the sort of work where I have time for thorough preparation and implementation
- ☐ 8. I regularly question people about their basic assumptions
- ☐ 9. What matters most is whether something works in practice
- ☐ 10. I actively seek out new experiences
- ☐ 11. When I hear about a new idea or approach I immediately start working out how to apply it in practice
- ☐ 12. I am keen on self discipline such as watching my diet, taking regular exercise, sticking to a fixed routine, etc
- ☐ 13. I take pride in doing a thorough job
- ☐ 14. I get on best with logical, analytical people and less well with spontaneous, 'irrational' people
- ☐ 15. I take care over the interpretation of data available to me and avoid jumping to conclusions
- ☐ 16. I like to reach a decision carefully after weighing up many alternatives
- ☐ 17. I'm attracted more to novel, unusual ideas than to practical ones
- ☐ 18. I don't like disorganised things and prefer to fit things into a coherent pattern
- ☐ 19. I accept and stick to laid down procedures and policies so long as I regard them as an efficient way of getting the job done
- ☐ 20. I like to relate my actions to a general principle
- ☐ 21. In discussions I like to get straight to the point
- ☐ 22. I tend to have distant, rather formal relationships with people at work
- ☐ 23. I thrive on the challenge of tackling something new and different
- ☐ 24. I enjoy fun-loving, spontaneous people
- ☐ 25. I pay meticulous attention to detail before coming to a conclusion
- ☐ 26. I find it difficult to produce ideas on impulse
- ☐ 27. I believe in coming to the point immediately
- ☐ 28. I am careful not to jump to conclusions too quickly
- ☐ 29. I prefer to have as many resources of information as possible – the more data to think over the better
- ☐ 30. Flippant people who don't take things seriously enough usually irritate me
- ☐ 31. I listen to other people's points of view before putting my own forward
- ☐ 32. I tend to be open about how I'm feeling
- ☐ 33. In discussions I enjoy watching the manoeuvrings of the other participants
- ☐ 34. I prefer to respond to events on a spontaneous, flexible basis rather than plan things out in advance

- ☐ 35. I tend to be attracted to techniques such as network analysis, flow charts, branching programs, contingency planning, etc
- ☐ 36. It worries me if I have to rush out a piece of work to meet a tight deadline
- ☐ 37. I tend to judge people's ideas on their practical merits
- ☐ 38. Quiet, thoughtful people tend to make me feel uneasy
- ☐ 39. I often get irritated by people who want to rush things
- ☐ 40. It is more important to enjoy the present moment than to think about the past or future
- ☐ 41. I think that decisions based on a thorough analysis of all the information are sounder than those based on intuition
- ☐ 42. I tend to be a perfectionist
- ☐ 43. In discussions I usually produce lots of spontaneous ideas
- ☐ 44. In meetings I put forward practical realistic ideas
- ☐ 45. More often than not, rules are there to be broken
- ☐ 46. I prefer to stand back from a situation
- ☐ 47. I can often see inconsistencies and weaknesses in other people's arguments
- ☐ 48. On balance I talk more than I listen
- ☐ 49. I can often see better, more practical ways to get things done
- ☐ 50. I think written reports should be short and to the point
- ☐ 51. I believe that rational, logical thinking should win the day
- ☐ 52. I tend to discuss specific things with people rather than engaging in social discussion
- ☐ 53. I like people who approach things realistically rather than theoretically
- ☐ 54. In discussions I get impatient with irrelevancies and digressions
- ☐ 55. If I have a report to write I tend to produce lots of drafts before settling on the final version
- ☐ 56. I am keen to try things out to see if they work in practice
- ☐ 57. I am keen to reach answers via a logical approach
- ☐ 58. I enjoy being the one that talks a lot
- ☐ 59. In discussions I often find I am the realist, keeping people to the point and avoiding wild speculations
- ☐ 60. I like to ponder many alternatives before making up my mind
- ☐ 61. In discussions with people I often find I am the most dispassionate and objective
- ☐ 62. In discussions I'm more likely to adopt a "low profile" than to take the lead and do most of the talking
- ☐ 63. I like to be able to relate current actions to a longer term bigger picture
- ☐ 64. When things go wrong I am happy to shrug it off and "put it down to experience"
- ☐ 65. I tend to reject wild, spontaneous ideas as being impractical
- ☐ 66. It's best to think carefully before taking action
- ☐ 67. On balance I do the listening rather than the talking
- ☐ 68. I tend to be tough on people who find it difficult to adopt a logical approach
- ☐ 69. Most times I believe the end justifies the means
- ☐ 70. I don't mind hurting people's feelings so long as the job gets done
- ☐ 71. I find the formality of having specific objectives and plans stifling
- ☐ 72. I'm usually one of the people who puts life into a party
- ☐ 73. I do whatever is expedient to get the job done
- ☐ 74. I quickly get bored with methodical, detailed work
- ☐ 75. I am keen on exploring the basic assumptions, principles and theories underpinning things and events
- ☐ 76. I'm always interested to find out what people think
- ☐ 77. I like meetings to be run on methodical lines, sticking to laid down agenda, etc.
- ☐ 78. I steer clear of subjective or ambiguous topics
- ☐ 79. I enjoy the drama and excitement of a crisis situation
- ☐ 80. People often find me insensitive to their feelings

SCORING AND INTERPRETING THE LEARNING STYLES QUESTIONNAIRE

The Questionnaire is scored by awarding one point for each ticked item. There are no points for crossed items. Simply indicate on the lists below which items were ticked by circling the appropriate question number.

	2	7	1	5
	4	13	3	9
	6	15	8	11
	10	16	12	19
	17	25	14	21
	23	28	18	27
	24	29	20	35
	32	31	22	37
	34	33	26	44
	38	36	30	49
	40	39	42	50
	43	41	47	53
	45	46	51	54
	48	52	57	56
	58	55	61	59
	64	60	63	65
	71	62	68	69
	72	66	75	70
	74	67	77	73
	79	76	78	80
TOTALS	________	________	________	________
	Activist	**Reflector**	**Theorist**	**Pragmatist**

LEARNING STYLES QUESTIONNAIRE PROFILE BASED ON GENERAL NORMS FOR 1302 PEOPLE

ACTIVIST	REFLECTOR	THEORIST	PRAGMATIST	
20	20	20	20	Very strong preference
19				
18		19	19	
17				
16		18		
15		17	18	
14				
13	18	16	17	
12	17	15	16	Strong preference
	16			
11	15	14	15	
10	14	13	14	Moderate
9	13	12	13	
8				
7	12	11	12	
6	11	10	11	Low preference
5	10	9	10	
4	9	8	9	
3	8	7	8	Very low preference
	7	6	7	
	6	5	6	
2	5	4	4	
	4	3	3	
	3			
1	2	2	2	
	1	1	1	
0	0	0	0	

LEARNING STYLES – GENERAL DESCRIPTIONS

Activists

Activists involve themselves fully and without bias in new experiences. They enjoy the here and now and are happy to be dominated by immediate experiences. They are open-minded, not sceptical, and this tends to make them enthusiastic about anything new. Their philosophy is: "I'll try anything once". They tend to act first and consider the consequences afterwards. Their days are filled with activity. They tackle problems by brainstorming. As soon as the excitement from one activity has died down they are busy looking for the next. They tend to thrive on the challenge of new experiences but are bored with implementation and longer-term consolidation. They are gregarious people constantly involving themselves with others but in doing so they seek to centre all activities on themselves.

Reflectors

Reflectors like to stand back to ponder experiences and observe them from many different perspectives. They collect data, both first hand and from others, and prefer to think about it thoroughly before coming to any conclusion. The thorough collection and analysis of data about experiences and events is what counts so they tend to postpone reaching definitive conclusions for as long as possible. Their philosophy is to be cautious. They are thoughtful people who like to consider all possible angles and implications before making a move. They prefer to take a back seat in meetings and discussions. They enjoy observing other people in action. They listen to others and get the drift of the discussion before making their own points. They tend to adopt a low profile and have a slightly distant, tolerant unruffled air about them. When they act it is part of a wide picture which includes the past as well as the present and others' observations as well as their own.

Theorists

Theorists adapt and integrate observations into complex but logically sound theories. They think problems through in a vertical, step-by-step logical way. They assimilate disparate facts into coherent theories. They tend to be perfectionists who won't rest easy until things are tidy and fit into a rational scheme. They like to analyse and synthesise. They are keen on basic assumptions, principles, theories models and systems thinking. Their philosophy prizes rationality and logic. "If it's logical it's good". Questions they frequently ask are: "Does it make sense?" "How does this fit with that?" "What are the basic assumptions?" They tend to be detached, analytical and dedicated to rational objectivity rather than anything subjective or ambiguous. Their approach to problems is consistently logical. This is their "mental set" and they rigidly reject anything that doesn't fit with it. They prefer to maximise certainty and feel uncomfortable with subjective judgments, lateral thinking and anything flippant.

Pragmatists

Pragmatists are keen on trying out ideas, theories and techniques to see if they work in practice. They positively search out new ideas and take the first opportunity to experiment with applications. They are the sorts of people who return from management courses brimming with new ideas that they want to try out in practice. They like to get on with things and act quickly and confidently on ideas that attract them. They tend to be impatient with ruminating and open-ended discussions. They are essentially practical, down to earth people who like making practical decisions and solving problems. They respond to problems and opportunities "as a challenge". Their philosophy is: "There is always a better way" and "if it works it's good".

In descending order of likelihood, the most common combinations are:

1st Reflector/Theorist
2nd Theorist/Pragmatist
3rd Reflector/Pragmatist
4th Activist/Pragmatist

LEARNING STYLES – A FURTHER PERSPECTIVE

ACTIVISTS:

Activists *learn best from activities where:*

- There are new experiences/problems/opportunities from which to learn.
- They can engross themselves in short "here and now" activities such as business games, competitive teamwork tasks, role-playing exercises.
- There is excitement/drama/crisis and things chop and change with a range of diverse activities to tackle
- They have a lot of the limelight/high visibility, i.e. they can "chair" meetings, lead discussions, and give presentations.
- They are allowed to generate ideas without constraints of policy or structure or feasibility.
- They are thrown in at the deep end with a task they think is difficult, i.e. when set a challenge with inadequate resources and adverse conditions.
- They are involved with other people, i.e. bouncing ideas off them, solving problems as part of a team.
- It is appropriate to "have a go".

Activists *learn least from, and may react against, activities where:*

- Learning involves a passive role, i.e. listening to lectures, monologues, explanations, statements of how things should be done, reading, watching.
- They are asked to stand back and not be involved.
- They are required to assimilate, analyse and interpret lots of "messy" data.
- They are required to engage in solitary work, i.e. reading, writing, thinking on their own.
- They are asked to assess beforehand what they will learn, and to appraise afterwards what they have learned.
- They are offered statements they see as "theoretical", i.e. explanation of cause or background
- They are asked to repeat essentially the same activity over and over again, i.e. when practicing.
- They have precise instructions to follow with little room for manoeuvre.
- They are asked to do a thorough job, i.e. attend to detail, tie up loose ends, dot the i's, cross t's.

Summary of strengths

- Flexible and open minded.
- Happy to have a go.
- Happy to be exposed to new situations.
- Optimistic about anything new and therefore unlikely to resist change.

Summary of weaknesses:

- Tendency to take the immediately obvious action without thinking.
- Often take unnecessary risks.
- Tendency to do too much themselves and hog the limelight.
- Rush into action without sufficient preparation.
- Get bored with implementation/consolidation.
- Key questions for activists:
- Shall I learn something new, i.e. that I didn't know/couldn't do before?
- Will there be a wide variety of different activities? (I don't want to sit and listen for more than an hour at a stretch!)
- Will it be OK to have a go/let my hair down/make mistakes/have fun?
- Shall I encounter some tough problems and challenges?
- Will there be other like-minded people to mix with?

REFLECTORS:

Reflectors *learn best from activities where:*

- They are allowed or encouraged to watch/think/chew over activities.
- They are able to stand back from events and listen/observe, i.e. observing a group at work, taking a back seat in a meeting, watching a film or video.
- They are allowed to think before acting, to assimilate before commencing, i.e. time to prepare, a chance to read in advance a brief giving background data.
- They can carry out some painstaking research, i.e. investigate, assemble information, and probe to get to the bottom of things.
- They have the opportunity to review what has happened, what they have learned.
- They are asked to produce carefully considered analyses and reports.

- They are helped to exchange views with other people without danger, i.e. by prior agreement, within a structured learning experience.
- They can reach a decision in their own time without pressure and tight deadlines.

Reflectors *learn least from, and may react against, activities where:*

- They are "forced" into the limelight, i.e. to act as leader/chairman, to role-play in front of on-lookers.
- They are involved in situations which require action without planning.
- They are pitched into doing something without warning, i.e. to produce an instant reaction, to produce an off-the-top-of-the-head idea.
- They are given insufficient data on which to base a conclusion.
- They are given cut and dried instructions of how things should be done.
- They are worried by time pressures or rushed from one activity to another.
- In the interests of expediency they have to make short cuts or do a superficial job.

Summary of strengths:

- Careful.
- Thorough and methodical
- Thoughtful
- Good at listening to others and assimilating information.
- Rarely jump to conclusions.

Summary of weaknesses:

- Tendency to hold back from direct participation.
- Slow to make up their minds and reach a decision.
- Tendency to be too cautious and not take enough risks.
- Not assertive - they aren't particularly forthcoming and have no "small talk".

Key questions for reflectors:

- Shall I be given adequate time to consider, assimilate and prepare?
- Will there be opportunities/facilities to assemble relevant information?
- Will there be opportunities to listen to other people's points of view – preferably a wide cross section of people with a variety of views?
- Shall I be under pressure to be slapdash or to extemporise?

THEORISTS:

Theorists *learn best from activities where:*

- What is being offered is part of a system, model, concept, or theory.
- The have time to explore methodically the associations and inter-relationships between ideas, events and situations.
- They have the chance to question and probe the basic methodology, assumptions or logic behind something, i.e. by taking part in a question and answer session, by checking a paper for inconsistencies.
- They are intellectually stretched, i.e. by analysing a complex situation, being tested in a tutorial session, by teaching high calibre people who ask searching questions.
- They are in structured situations with a clear purpose.
- They can listen to or read about ideas and concepts that emphasise rationality or logic and are well argued/elegant/watertight.
- They can analyse and then generalise the reasons for success or failure.
- They are offered interesting ideas and concepts even though they are not immediately relevant.
- They are required to understand and participate in complex situations.

Theorists *learn least from, and may react against, activities where:*

- They are pitch-forked into doing something without a context or apparent purpose.
- They have to participate in situations emphasising emotions and feelings.
- They are involved in unstructured activities where ambiguity and uncertainty are high, i.e. with open¬ended problems, on sensitivity training.
- They are asked to act or decide without a basis in policy, principle or concept.
- They are faced with a hotchpotch of alternative/contradictory techniques/methods without exploring any in depth, i.e. as on a "once over lightly" course.
- They find the subject matter platitudinous, shallow or gimmicky.
- They feel themselves out of tune with other participants, i.e. when with lots of Activists or people of lower intellectual calibre.

Summary of strengths:

- Logical "vertical" thinkers.
- Rational and objective.
- Good at asking probing questions.
- Disciplined approach.

Summary of weaknesses:

- Restricted in lateral thinking.
- low tolerance for uncertainty, disorder and ambiguity
- Intolerant of anything subjective or intuitive.
- Full of "shoulds, oughts and musts".

Key questions for theorists:

- Will there be lots of opportunities to question?
- Do the objectives and program of events indicate a clear structure and purpose?
- Shall I encounter complex ideas and concepts that are likely to stretch me?
- Are the approaches to be used and concepts to be explored "respectable", i.e. sound and valid?
- Shall I be with people of similar calibre to myself?

PRAGMATIST:

Pragmatists *learn best from activities where:*

- There is an obvious link between the subject matter and a problem or opportunity on the job.
- They are shown techniques for doing things with obvious practical advantages, i.e. how to save time, how to make a good first impression, how to deal with awkward people.
- They have the chance to try out and practice techniques with coaching/feedback from a credible expert, i.e. someone who is successful and can do the techniques themselves.
- They are exposed to a model they can emulate, i.e. a respected boss, a demonstration from someone with a proven track record, lots of examples/anecdotes, and a film showing how it's done.
- They are given techniques currently applicable to their own job.
- They are given immediate opportunities to implement what they have learned.
- There is a high face validity in the learning activity, i.e. a good simulation, "real" problems.
- They can concentrate on practical issues, i.e. drawing up action plans with an obvious end product, suggesting short cuts, giving tips.

Pragmatists *learn least from, and may react against, activities where:*

- The learning is not related to an immediate need they recognise/they cannot see, an immediate relevance/practical benefit.
- Organisers of the learning, or the event itself, seems distant from reality, i.e. "ivory towered", all theory and general principles, pure "chalk and talk".
- There is no practice or clear guidelines on how to do it.
- They feel that people are going round in circles and not getting anywhere fast enough.
- There are political, managerial or personal obstacles to implementation.
- There is no apparent reward from the learning activity, i.e. more sales, shorter meetings, higher bonus, promotion.

Summary of strengths:

- Keen to test things out in practice.
- Practical, down to earth, realistic.
- Businesslike – gets straight to the point.
- Technique oriented.

Summary of weaknesses:

- Tendency to reject anything without an obvious application.
- Not very interested in theory or basic principles.
- Tendency to seize on the first expedient solution to a problem.
- Impatient with waffle.
- On balance, task oriented not people oriented.

Key questions for pragmatists:

- Will there be ample opportunities to practice and experiment?
- Will there be lots of practical tips and techniques?
- Shall we be addressing real problems and will it result in action plans to tackle some of my current problems?
- Shall we be exposed to experts who know how to/can do it themselves?

GLOSSARY

ACRONYMS, ABBREVIATIONS AND UNITS OF MEASUREMENT

AWEX	Australian Wool Exchange
CMC	cell membrane complex
CVD	coefficient of variation of diameter
DFE	directional friction effect
DSC	differential scanning calorimetry
LOI	limiting oxygen index
MFD	mean fibre diameter
RH	relative humidity
SFE	surface free energy
SPF	sun protection factor
UV	ultraviolet
VM	vegetable matter
μm	micron
Tg	glass transition temperature

GLOSSARY

Term	Definition
α (alpha)-helix	one of the most basic components of the wool fibre cells, which forms the crystalline regions of the wool fibre.
18-methyleicosanic acid (18-MEA)	an organic acid that is a major component of the F-layer, which provides the hydrophobic (water-resistant) surface on the fibre.
abrasion resistance	the ability of the wool fibre to resist damage during wear.
adsorption	the process where by which wool fibres take in moisture as water vapour from the surrounding air.
ageing	the temporary change of some of the physical properties of wool fibres with time, such as stiffness and rate of stress relaxation. Ageing only occurs below the glass transition temperature (Tg).
Allworden bubbles	the bubbles or sacs that develop on the surface of the wool fibre when it is placed in a chlorine or bromine solution in water. They contain solubilised protein from the exocuticle.
amide bond	the link formed between amino acids, sometimes called a peptide bonds.
amino acid	a naturally-occurring compound containing both an amino and a carboxylic acid group. Amino acids are the building blocks of protein and can be grouped according to their type — there are 22 different amino acids.
ammonium	an amine (-NH3+) side group that has been ionised and positively charged under appropriate low pH (acid) conditions.
amorphous	non-crystalline in form.
anisotropic swelling	where the swelling of the wool fibre differs in magnitude according to the direction of measurement. As wool adsorbs moisture, the greatest swelling occurs in the diameter.
anti-setting agents	substantive electrophilic compounds that react with free thiol groups, reducing the number of free ionised thiol groups and therefore reducing the rate of permanent setting.
aramid	a heat-resistant and strong synthetic fibre used in aerospace and military applications.
aspartic acid	an amino acid with a carboxyl (-COOH) side group, which can become ionised and negatively charged (carboxylate) under high pH (alkaline) conditions.
atopic dermatitis	see eczema
Australian Wool Exchange (AWEX)	Australian Wool Exchange, a public company that manages and administers wool marketing arrangements in the Australian wool industry.

Term	Definition
bending rigidity	the greater the diameter of the wool fibre, the stiffer or more rigid the fibre (and resultant fabric) is.
beta layer	a part of the cell membrane complex (CMC) — the lipid that adheres to the resistant cell membrane surrounding the cortical cell.
bilateral distribution	distributed so the components are not mixed, but restricted to opposite sides of the fibre cross-section.
biodegradable	a substance that will decompose naturally.
breathability	the ability of a fabric to allow moisture vapour to be transmitted through the material.
'bricks, mortar and tile' model	a simplistic model developed by the CSIRO during the 1980s to explain the structure of wool for the purpose of processing. The 'tiles' represent the cuticle cells, the 'bricks' represent the cortical cells and the 'mortar' represents the cell membrane complex (CMC).
bursting strength	wet strength of the wool fabrics, a useful indicator of fibre damage.
carboxylate	see aspartic acid.
cell membrane complex (CMC)	separates the cortical cells from each other and the cortical cells from the cuticle cells. The CMC contains a waxy lipid material, comprises ~6% of the total fibre weight and provides the primary pathway for dye to enter into the interior of the fibre.
coefficient of variation of diameter (CVD)	a statistical measure of the variability exhibited within a set of fibre diameter values. It expresses the standard deviation as a percentage of the mean; the higher the CVD, the greater the variability in wool fibre diameter.
cohesive set	set released when wool is wet out or heated in water at 20°C.
conditioning	the process of equilibration of moisture content between wool fibres and the surrounding air. The rate of conditioning depends on the circulation of air and, to a lesser extent, air temperature.
cortical cells	cells on the inside of the wool fibre, made up of microfibrils and macrofibrils, which form the bulk of the wool fibre and are largely responsible for the mechanical properties of the fibre, such as moisture and dye uptake, tensile and bending properties, fibre crimp and stress relaxation properties.
covalent bond	a strong chemical bond formed by the sharing of electrons between atoms.
creep	the rate of extension when under constant tensile load (tensile property).
crimp	the waviness of a fibre, expressed numerically as the number of complete waves per unit length. Crimp is sometimes taken as an indicator of mean fibre diameter (MFD) — the higher the number of crimps per unit length, the finer the wool (although the correlation is not perfect).

Term	Definition
crystallinity	describes the wool fibre's stiffness, strength and resilience. The crystalline regions of the wool fibre are the ordered regions of the fibres containing the alpha helical components.
cuticle cells	cells that form the scales on the outside of the wool fibre.
cysteine	an amino acid with a sulphur side group. Cysteine side groups tend to form disulphide groups with other cysteine side groups.
cystine	one of the most important amino acids because it forms covalent crosslinks (also known as disulphide bonds) between adjacent protein chains (also known as disulphide bonds).
cytoplasmic remnants	found in the cortical cells and make up ~%4 of the cross-sectional area of the wool fibre.
de-ageing	where the effects of ageing are removed, usually by steaming or wetting. De-ageing occurs above the glass transition temperature (Tg).
decatising	a steaming process that imparts flat set to wool fabrics.
deformation	the shape of a wool product is changed— can be permanent or temporary.
delipidised	wool fibres with the surface lipid layer removed.
delta layer	part of the cell membrane complex that provides adhesion between the cortical cells varies in thickness. The delt-layer dissolves in formic acid (or with enzymes) and is also called 'intercellular cement'.
desorption	describes the release of moisture (drying out) of wool fibres.
Devoré	a technique used on a blend fabric where a chemical process is used to dissolve one component fibre to create a semi-transparent pattern against more solidly woven fabric, leaving the other component fibres unaffected.
differential scanning calorimetry (DSC)	process used to measure the thermal capacity and glass transition temperature (Tg) of the wool fibre.
differential thermal analysis	method used to measure the temperature difference between a polymer and a standard. Differential thermal analysis is used to determine the glass transition temperature (Tg) of the wool fibre.
diglycerides	example of a naturally-occurring water-insoluble molecule (lipid).
dimensional change	can be shrinkage (both relaxation and felting shrinkage) or growth of a yarn, fabric or garment. Shrinkage is also called consolidation.
directional friction effect (DFE)	the difference in resistance when a fibre is rubbed in one direction when compared with the opposite direction. The DFE is the result of scales overlapping each other in a single direction along the fibre.

Term	Definition
disulphide crosslinks	also known as a disulphide bonds, formed during wool fibre growth through process known as 'keratinisation'. Disulphide crosslinks also make keratin fibres insoluble in water and more stable to physical and chemical attack.
disulphide interchange	an extremely important process in wool processing where disulphide crosslinks can be rearranged with the resulting formation of new disulphide crosslinks (disulphide bonds), allowing the wool fibre to take up a new permanent shape.
drape	how the fabric hangs.
dry felting	caused by mechanical action on 'damp' wool and can occur when wool adsorbs large amounts of water, but not enough to feel 'wet'. Dry felting occurs slowly and is observed in wool-filled pillows and quilts.
eczema	an allergic condition where the skin becomes dry, leading to cracking, bacterial infection, redness and itching, see atopic dermatitis.
electrophilic	a molecule that can accept an electron pair to make a covalent bond.
endocuticle	the inner layer of the cuticle cell.
enzymes	proteins that act as catalysts within living cells, increasing the rate at which chemical reactions occur without being consumed or permanently altered themselves.
epicuticle	the second layer of the cuticle cell, sometimes viewed as the proteolipid layer when combined with the F-layer. It is the resistant membrane surrounding the cuticle cells within the fibre.
exocuticle	the hard layer of the cuticle cell below the surface epicuticle, which comprises of two layers — exocuticle A and exocuticle B — and forms %60 of the cuticle cell.
exothermic	process where energy is released (occurs as wool adsorbs moisture, increasing the temperature of the fibre).
extensibility	the amount the wool fibre extends (stretches) under load.
F-layer	the outer layer of the cuticle cell, sometimes viewed with the proteolipid layer when combined with the epicuticle. The F-layer is hydrophobic, controls the 'wetting' properties and friction between the fibres and determines the surface free energy (SFE) of the wool fibre.
felt resistance	the ability of a wool garment to resist felting shrinkage during wear and care (i.e. laundering). Felt resistance can be imparted to wool at various stages during processing using a variety of treatments.
felting shrinkage	the shrinkage that occurs when a damp or wet fabric is subjected to a mechanical action that entangles the fibres. It is seen as a matting of the fabric and results in an irreversible, drastic reduction in dimensional size of garment.

Term	Definition
fibre tenacity	strength of fibre (measured in N/Tex).
fleece	the main wool covering the sheep's back and sides. The fleece usually comes off in one large piece, which is thrown across the wool table for skirting.
free ionised thiol groups	thiol groups from which the hydrogen atom has been removed under high pH (alkaline conditions). This catalyses disulphide interchange to occur between the wool fibres, which then determines the amount of permanent set.
glass transition	a change in properties of polymers, such as wool, from a stiffer, 'glassy' state to a softer, 'rubbery or fluid' state. Glass transition is a second order phase transition associated with the non-crystalline regions of polymers.
glass transition temperature (Tg)	the temperature at which wool fibres change from a glassy state to rubbery state and is associated with a significant change in stiffness.
glutamic acid	an amino acid with a carboxyl (-COOH) side group, which can become ionised and negatively charged (carboxylate) under high pH (alkaline) conditions.
handle	'feel' of the wool fabric — the feel can be harsh and stiff or soft and easily deformed.
Hercosett	a water-soluble epichlorhydrin-functional polyamide.
histidine	an amino acid with an amine(-NH2) side group, which can become ionised and positively charged (ammonium) under low pH (acid) conditions. Lysine and arginine are examples of this type of amino acid.
homogeneous	uniform in structure and composition.
hydrolysis	a type of chemical reaction where one reactant is water.
hydrophobic	water repelling
hydroxy radicals	contribute to the photo-yellowing of wool by attacking susceptible amino acids and forming coloured species. This process occurs more rapidly in wet wool compared to with dry.
hygroscopic	the ability to adsorb water from the surrounding environment until it comes to an equilibrium with the surrounding air. Wool exhibits this ability.
hysteresis	hysteresis is the effect observed under given conditions of temperature and relative humidity (RH) of the surrounding air, where the equilibrium moisture content of the fibre will be higher when drying (desorption) than when it is conditioning from a dry state (adsorption).
insensible perspiration	water vapour next to the skin due to perspiration by humans not requiring activity. Insensible perspiration refers to the perspiration that happens before it is perceived or 'sensed' where there is no loss of pure water and no associated loss of solute. This is in contrast to sensible perspiration.

Term	Definition
ionic crosslinks	form between positively and negatively charged side groups, sometimes called 'salt links', and have a stabilising effect on wool proteins by reducing damage and swelling when they are wet.
iso-electric point	the pH at which a molecule carries no net electrical charge —this is ~4.5 for the wool fibre.
iso-peptide crosslinks	example of covalent crosslinks (bonds) between polymer chains, formed by condensation of acid side groups and amino side groups to form an amide (covalent bond). These bonds are difficult to detect and low in number.
keratin	the main constituent of wool, keratin is a complex of proteins characterised by sulphur content, with cystine being the important amino acid present. There are about 170 different keratins present in the wool fibre.
lanolin	a chemical compound derived from wool wax, which covers the wool fibre, often used in cosmetics.
lanthionine crosslink	example of a covalent crosslink (bond) between polymer chains, formed under alkaline conditions by beta-elimination of sulphur from a cystine crosslink, where cystine becomes a new amino acid called lanthionine.
limiting oxygen index (LOI)	the minimum concentration of oxygen, expressed as a percentage, that will support combustion of a polymeric material (e.g. wool).
lysoalanine crosslink	example of covalent crosslink (bond) between polymer chains, formed under alkaline conditions by attack of the amino group on cystine.
macrofibrils	components of the cortical cell, ~0.3 μm diameter, which contain the microfibrils.
mean fibre diameter (MFD)	The arithmetic mean (average) of all fibre diameter readings in a sample.
MEAS	reducing agent used to increase the rate of permanent set by increasing the concentration of free ionised thiol groups that catalyse thiol-disulphide interchange between wool fibres.
medulla	a central core of cells containing an air-filled space, found in broad wool fibres, which improves the insulation value of the fleece.
melanin	a dark biological pigment or biochrome. Melanin gives animal fibres, such as wool, their colour.
melting point	the temperature at which crystalline or semi-crystalline matter changes completely from a solid material to a fluid or rubbery material.
Merino	a type of sheep breed specifically developed to produce high-–quality wool.
meso-cortical cell	a type of cortical cell — makes up ~4% of the wool fibre.

Term	Definition
microfibrils	rod-like components found within the macrofibrils of the cortical cells. Microfibrils are crystalline, also called 'intermediate filaments', and are ~0.007 μm in diameter.
Micron (μm)	a millionth of a metre (micrometre μm) and the unit of measurement used to describe wool fibre diameter.
modulus	the stiffness of a polymeric material, which is affected by temperature and moisture content.
moisture sorption	the process whereby wool adsorbs water vapour from the surrounding air, can be up to 35% of its own weight, affected by relative humidity and air temperature (to a lesser extent).
monoglycerides	example of a naturally-occurring water-insoluble molecule (lipid).
natural fibres	natural fibres are those which occur naturally and come directly from either plant or animal sources.
nuclear remnants	present in keratin structures and derived from cortical cells in the growing fibre.
nucleophilic	used to describe amino acids that will form associations with water molecules and other polar molecules.
ortho-cortical cell	a type of cortical cell, which is more crystalline, contains less sulphur, takes up dye more slowly, is more reactive and swells less than a para-cortical cells. Ortho-cortical cells are also found in a more helical (twisted) conformation than para-cortical cells.
oxidant	a reactant, such as chlorine and peroxides, which can oxidise or remove electrons from other reactants, used to degrade the cuticle cells on the wool fibre surface to reduce directional friction effect (DFE) and impart felt resistance.
oxidation	the loss of electrons during a reaction.
para-cortical cell	a type of cortical cell, which is less crystalline, contains more sulphur, takes up dye quickly, and swells more than ortho-cortical cells. Para-cortical cells are found in a straighter conformation than ortho-cortical cells.
permanent set	the process whereby the shape of a wool product is permanently changed by deforming it under conditions where it will not return to its original shape. Permanent set fabrics are stable to release in water at 70°C for 30 minutes.
phenylalanine	a non-polar amino acid with an aromatic ring side group. Phenylalanine is a reactive amino acid, which forms coloured products and is associated with the yellowing of wool in sunlight.
pilling	friction causes loose fibres on the surface of a fabric to start entangling until little balls of fluffy fibres (pills) have formed.

Term	Definition
plasma treatment	alternative treatment to chemical degradation to reduce felting by degrading cuticle cells on the surface of the wool fibres by creating holes in the F-layer and epicuticle. An example of this process is Naturetexx Plasma by Sudwolle.
polar crosslinks	relatively weak intermolecular crosslinks (bonds), which form between hydrophilic side chains in addition to the amide (peptide) groups forming the polymer chains. Polar crosslinks are primarily responsible for the stability and properties of dry wool.
polar solvents	methanol-butanol and formic acids, used to improve abrasion resistance by modifying the cell membrane complex (CMC).
polyacrylate emulsion	a polymer formulation used to impart felt resistance in woven wool fabrics. It prevents relative motion of the fibres in the yarns (and thus felting) as mechanical action is applied.
polymer	a large molecule, or macromolecule, composed of many repeated subunits. Wool is a polymeric substance.
polypeptides	protein chains formed by links of amino acids.
polyurethane dispersion	A polymer formulation applied to wool fabrics to impart felt resistance.
post-yield zone	the region of the load extension curve, immediately after the initial 'stiff' region, where the slope of the load extension curve becomes lower.
pressure decatising	a high-temperature steaming process used to impart permanent set to wool fabric.
prickle	an itchy or prickly sensation caused by garments that contain a significant number of fibres > 30µm. Prickle factor depends largely on the structure of the garment, the sensitivity of the wearer and the conditions of wearing.
protease	an enzyme that catalyses reactions involving the breakdown of cuticle cells to impart felt resistance by reducing the directional friction effect (DFE).
proteolipid layer	a term used to describe the F-layer and epicuticle on the surface of the cuticle cells where the sulphur content is low.
protonation	the addition of a proton to an atom, molecule or ion.
rag pulling	retrieval of fibre from wool products at the end of their usable life.
regain	the mass of moisture in a mass of textile fibres determined under prescribed conditions, expressed as a percentage of the clean oven-dry mass of fibre.
relative humidity (RH)	the amount of water vapour present in air expressed as a percentage of the amount required for saturation at the same temperature.

Term	Definition
relaxation	is the process in which residual stresses and strains in wool are allowed to relax by immersing it in water, or exposing it to steam.
relaxation shrinkage	is the dimensional change that occurs when a yarn or fabric is allowed to relax by immersing it in water, or exposing it to steam. It is reversible, under specific conditions and happens when residual stresses and strains in wool are allowed to relax.
renewable	resources that can be replenished after they have been used.
sensible perspiration	liquid water on the skin due to the process of sweating under moderate activity.
serine	amino acid with a hydroxyl (-OH) side group. These groups are polar and can bond to other polar molecules (e.g. water) and can act as sites for association with adsorbed water.
shearing	removing the wool from the sheep using specially-designed handpieces.
Siroset	a process that uses a reducing agent to facilitate permanent setting of creases and pleats in woven apparel.
staple	a well-defined bundle of fibres that has been removed from a mass of greasy wool as a unit.
sterols	example of a lipid (water-insoluble molecule) and a significant component of the wool fibre.
stiffness	the force required to stretch the fibre and the load to bend the fabric. The lower the temperature, the stiffer the fibre.
stress recovery	the amount the fibre recovers when the extension load is released and the extent to which fibres recover when the bending couple is removed
stress relaxation	the decay in the force required to hold the fibre at constant extension and the decay on the load to hold a fibre bent .
sun protection factor (SPF)	a relative measure of how well a material or substance can screen or block harmful ultraviolet (UV) rays from the sun, the higher the SPF number, the greater the protection from harm.
super contraction	shortening of wool yarn, which occurs at 150°C when yarn is placed in sealed, water-filled melting point tube. Super contraction is associated with the melting of the crystalline regions within the fibre.
surface free energy (SFE)	the measure of the ease with which wool fibres can be wet by liquids, such as water, and to which some materials adhere.
synthetic fibres	fibres which do not occur naturally and are produced in laboratories using chemical compounds, which are predominantly petroleum-based.
temporary set	set that is stable to water at 20°C, but lost when immersed in water at 70°C for 30 minutes.
tensile property	the ability of a material to react to forces being applied under tension.

Term	Definition
thermal conductivity	the property of a material to conduct heat. When exercising, wool garments can absorb sweat as moisture, transporting it and associated heat away from the body, helping to keep the body cooler in the process.
thio-ester bond	weak bonds that hold the lipid layer (F-layer major component is 18-MEA) on the surface of the wool fibre, by breaking this bond, the lipid layer can be removed.
thioglycolic acid	example of thiol (-SH-) compound that can break the cystine disulphide crosslinks, which occur between the protein chains within the wool fibre.
thiol compounds	see thioglycolic acid, also hydrogen sulphide (H2S) as examples of thiol (-SH-) compounds that can break the cystine disulphide crosslinks, which occur between the protein chains within the wool fibre.
threonine	amino acid with a hydroxyl (-OH) side group. These groups are polar and can bond to other polar molecules (e.g. water) and can act as sites for association with adsorbed water.
top	a sliver of wool fibres combed to make a substantially parallel formation of fibres, free of vegetable matter.
triglycerides	example of a naturally-occurring water-insoluble molecule (lipid).
tryptophan	a highly reactive amino acid, which forms coloured products and is associated with the yellowing of wool in sunlight.
vegetable matter (VM)	burrs (including hard heads), twigs, seeds, leaves and grasses present in raw wool.
wettability	wettability refers to the ability of the wool fibre to be coated or wet by liquid water.
wrinkle recovery	the ability of the wool fibre to recover its original shape when the deforming (bending) force is removed. Aged wool garments have better wrinkle recovery than those that have been dry-cleaned or washed.
yellowing	the discolouration of wool, which is caused by the degradation or oxidation of specific amino acids resulting in the production of coloured species. Yellowing, occurs when wool is exposed to ultraviolet (UV) light, high pH (alkaline conditions) and heat (especially if moisture content is high).
yield	the amount of clean fibre, at a standard regain (moisture content) expected to be produced when raw wool is cleaned. Yield can be expressed both as a clean mass in kilograms and as a percentage of the mass of raw wool before processing.
yield point	the point at which the slope of the load extension curve changes.
yield zone	the region of the load extension curve immediately after the yield point.

COURSE
INTRODUCTION

THE
WOOLMARK
COMPANY

WOOL FIBRE SCIENCE

WELCOME participants as they arrive, ensuring they collect their pre-prepared name tags or ask them to write their name on a tag as they arrive.

ENSURE each participant takes a copy of the Participant Guide and records their attendance.

INTRODUCE yourself and provide a brief (maximum three-minute) overview of your role, experience and broad objectives in delivering this series of lectures.

After introducing yourself, if you have a group of 20 participants or less, ask each participant to provide a brief introduction (name, role and organisation, or area of study) and share three things they wish to achieve by attending this series of lectures.

NOTE: If you have 20 students and they each take about 30 seconds to introduce themselves and their objectives, this exercise will require 10 minutes.

Keep it brief. You may need to modify your approach, based on the number of students in the room. For example, in a large group (20+ students select a small sample of students to introduce themselves and share their expectations).

RECORD AND group participants' responses regarding their own learning objectives on the flipchart or whiteboard.

This introduction will expand upon your understanding of each participant's needs and attitude towards their participation in the program and will give them the opportunity to build rapport with you as the facilitator and other participants in the group.

EXPLAIN TO students you will revisit these objectives throughout the course to ensure each objective has been covered or students are directed to additional resources that will help them meet their own learning objectives.

Endeavour to draw on these participant objectives as you progress through the course.

SPEND a few moments exploring participants current understanding of wool. Establishing how much individuals, or the group as a whole, already knows about wool will allow you to acknowledge and leverage the experience of those in the room and tailor the content and delivery of the course appropriately to either dispel misperceptions or build on current understanding.

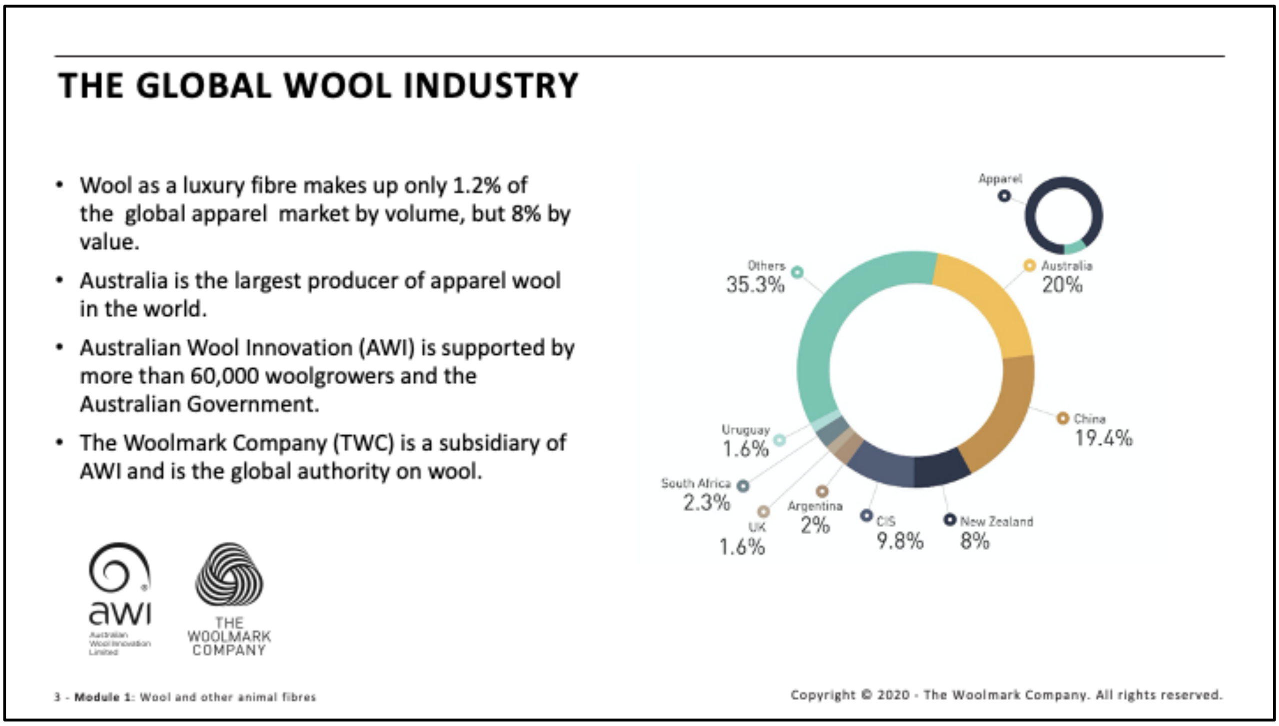
ALLOW about 5–10 minutes for a group discussion prompted by a questioning approach outlined below.

ASK participants to share what they already know about wool.

Examples of questions you might ask to encourage participation include:
- Where does wool come from?
- Is wool a natural or synthetic fibre?
- Do you own any wool garments or furnishings?
- What are some key characteristics of wool garments?

RECORD responses to the above questions on a flipchart or whiteboard and explain that you will re-visit the responses at the end of this module and the course to reflect upon what participants may have learnt during the course.

NOTE: *If participants have not already been introduced to Australian Wool Innovation (AWI) and The Woolmark Company (TWC) insert this short presentation here, before continuing with* Module 1 — Wool and other animal fibres.



REFER TO the slide as you indicate that Australian woolgrowers produce 90% of the world's fine apparel wool as part of Australia's $2.5 billion wool export industry*.

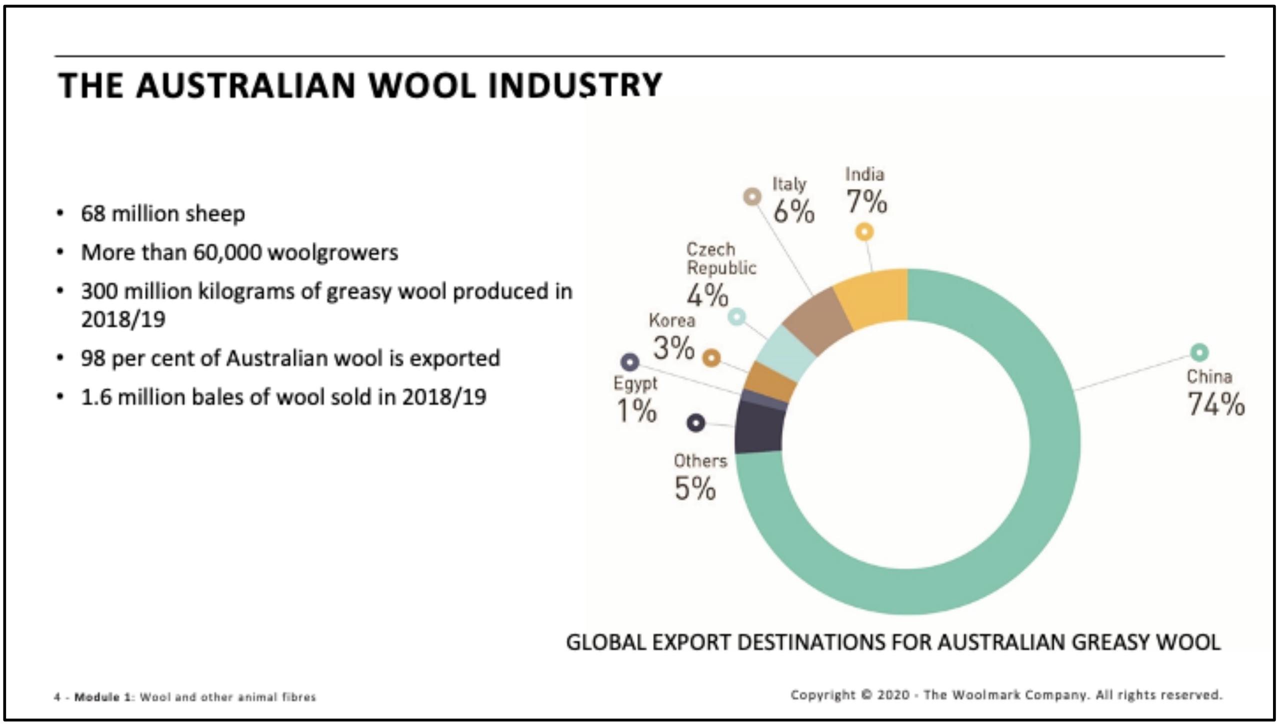
**Source ABARES Agricultural Commodities, March 2020 quarter.*

EXPLAIN THAT Australian Wool Innovation (AWI) is the research, development and marketing body for the Australian wool industry, supported by more than 60,000 Australian woolgrowers, who co-invest with the Australian government to support the activities carried out by AWI and TWC along the global wool supply chain.

EXPLAIN THAT The Woolmark Company is a subsidiary of Australian Wool Innovation and is a global authority on Merino wool. With a network that spans the entire global wool supply chain The Woolmark Company builds awareness and promotes the unique traits of nature's finest fibre.

REINFORCE THAT The Woolmark Company collaborates with global experts on all aspects of wool science, technology and design to develop and deliver educational materials, such as the course you are about to deliver.

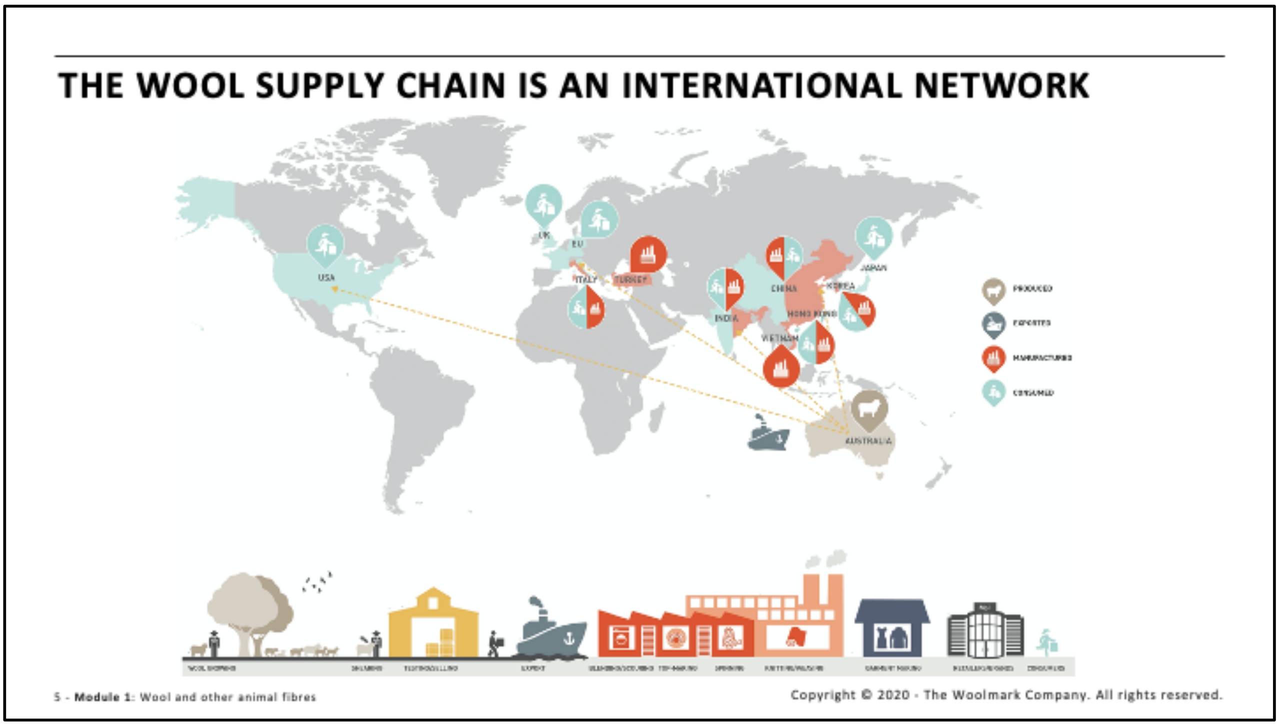
NOTE THAT you will provide a brief overview of the Australian wool industry and global supply chain, and elaborate on the role of The Woolmark Company in the global context before commencing the technical components of the course



EXPLAIN THAT there are more than 68 million sheep in Australia, carefully managed by more than 60,000 woolgrowers.

INDICATE THAT in 2018/19 Australia's woolgrowers produced 300 million kilograms of greasy wool and sold 1.6 million bales of wool.

POINT OUT that 98 per cent of Australia's wool is exported to other countries for further processing into a diverse range of products.



REFER TO the slide as you explain that it offers a snapshot of the global dynamics of the Australian wool industry, illustrating where the key export markets are for Australian wool, where most wool is processed from its raw state into yarn and fabrics and where the fashion and trend influencers and wool consumers are located.

NOTE THAT countries such as China, India and Italy are major manufacturers and consumers of wool products.

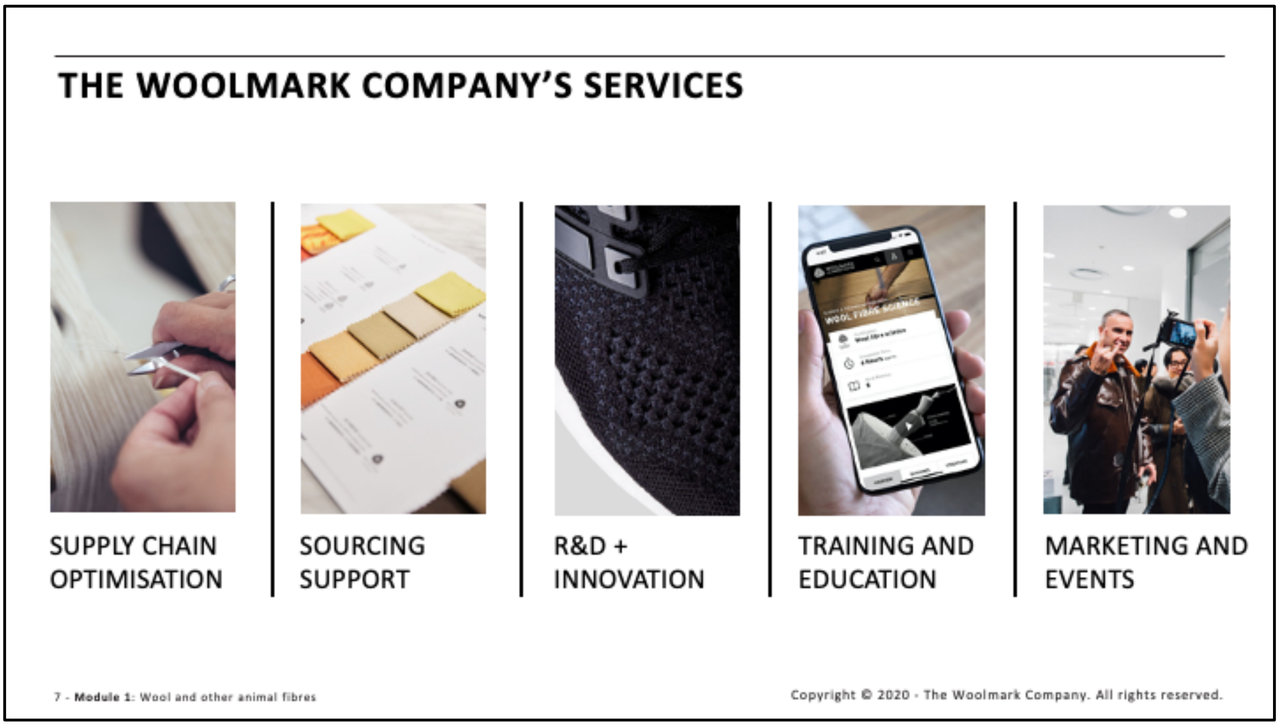
EXPLAIN THAT in line with these global dynamics, The Woolmark Company head office in Sydney, Australia is supported by a growing number of regional offices globally. Through this support The Woolmark Company invests in innovation along the global wool supply chain.

REINFORCE THAT The Woolmark Company works on behalf of Australia's 60,000+ woolgrowers, who are responsible for producing 90 per cent of the world's fine apparel wool.

EXPLAIN THAT The Woolmark Company's parent body — Australian Wool Innovation — invests in on-farm research and development to deliver new knowledge to woolgrowers to increase the profitability and sustainability of the growing wool business.

NOTE THAT The Woolmark Company strives to deliver tangible solutions across the global wool textile industry through process and product research and development.

EXPLAIN THAT the Woolmark Company builds industry confidence through communication, collaboration and a range of educational programs across the industry.



EXPLAIN THAT The Woolmark Company partners with designers, brands and retailers worldwide, offering support with quality assurance, product innovation and supply chain assistance.

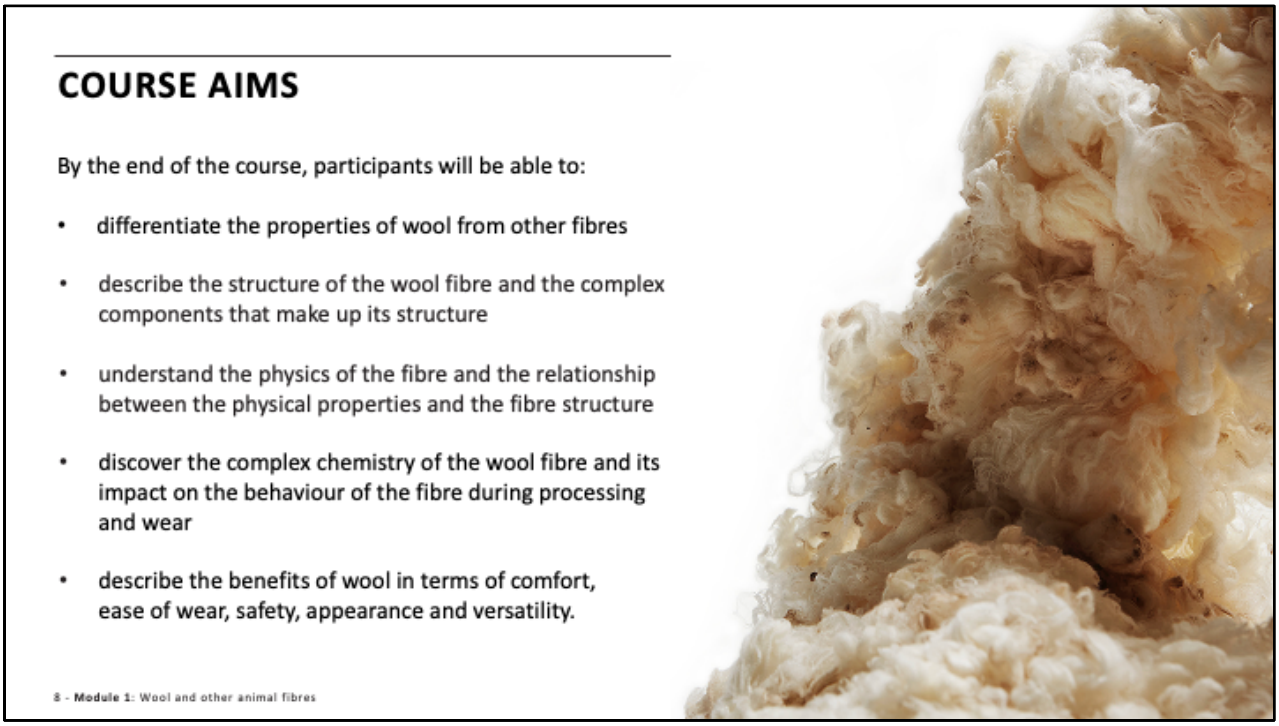
INDICATE THAT The Woolmark Company provides sourcing support through direct access to the global wool manufacturing industry through The Wool Lab. A seasonal guide to the latest innovations in wool, fabrics are sourced from the world's best spinners and weavers in the global supply network.

REINFORCE THAT The Woolmark Company ~~takes~~ secures funding and delivers research to improve wool production and processing through fibre science, traceability and fibre advocacy.

EXPLAIN THAT The Woolmark Company offers a range of online and face-to-face training programs to educate the industry. During 2019, The Woolmark Company launched the Woolmark Learning Centre, an online educational hub for industry professionals.

POINT OUT that The Woolmark Company markets the performance and environmental benefits of the fibre to ensure industry and consumers are informed and inspired to make better purchasing choices.

ASK PARTICIPANTS if they have any questions about the Woolmark Company before you proceed with the course aims.

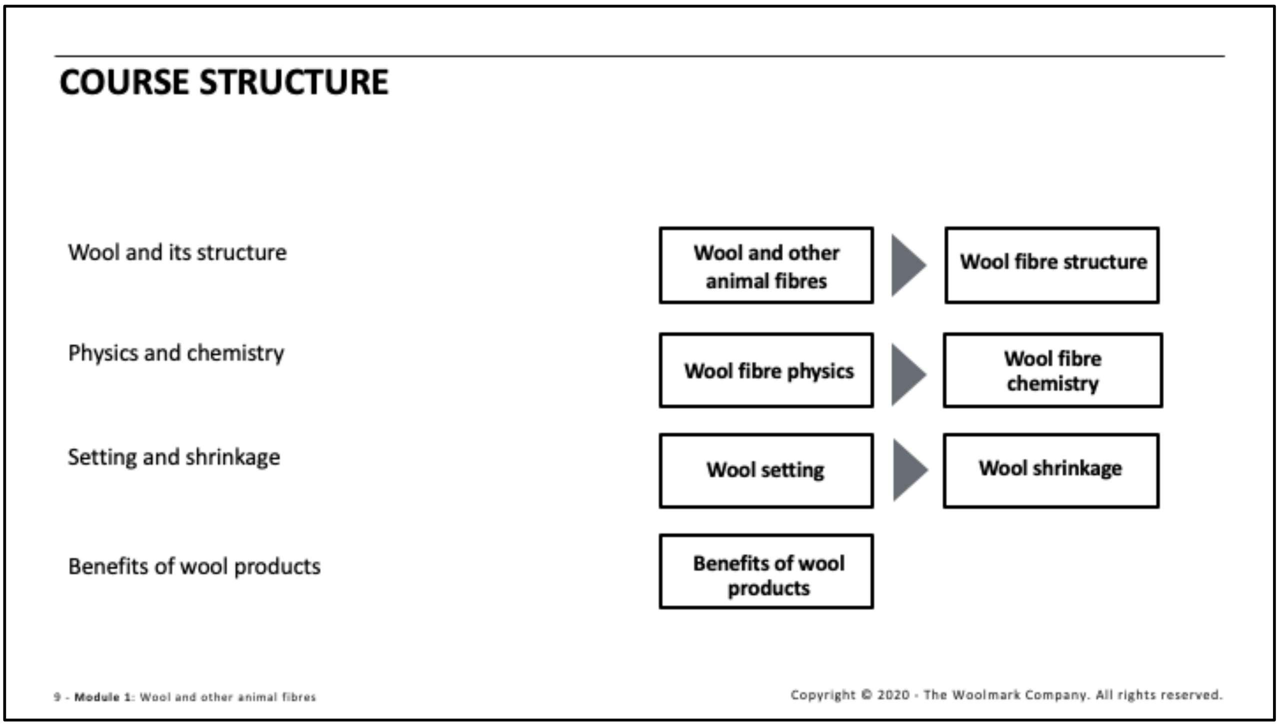


INSTRUCT participants to read the course aims for the course on the slide and remind them these aims are included in their Participant Guide.

EXPLAIN THAT the aim of this course is to introduce the participants to wool and to wool products.

INFORM participants that at the end of this course they will be able to:

- differentiate the properties of wool from other fibres
- describe the structure of the wool fibre and the complex components that make up its structure
- explain the physics of the fibre and the relationship between the physical properties and the fibre structure and chemistry
- outline the complex chemistry of the wool fibre and its impact on the behaviour of the fibre during processing and wear
- describe the benefits of wool in terms of comfort, ease of wear and care, safety, appearance and versatility.



EXPLAIN TO participants that the sequence of the following information may differ from the actual presentation to allow for differences in venue and participant prior knowledge and experience.

DIRECT participants to the relevant slide in the Participant Guide and run through the course structure as outlined on the slide and below.

EXPLAIN THAT this course takes an in-depth look at the wool fibre, its structure, chemistry and physics.

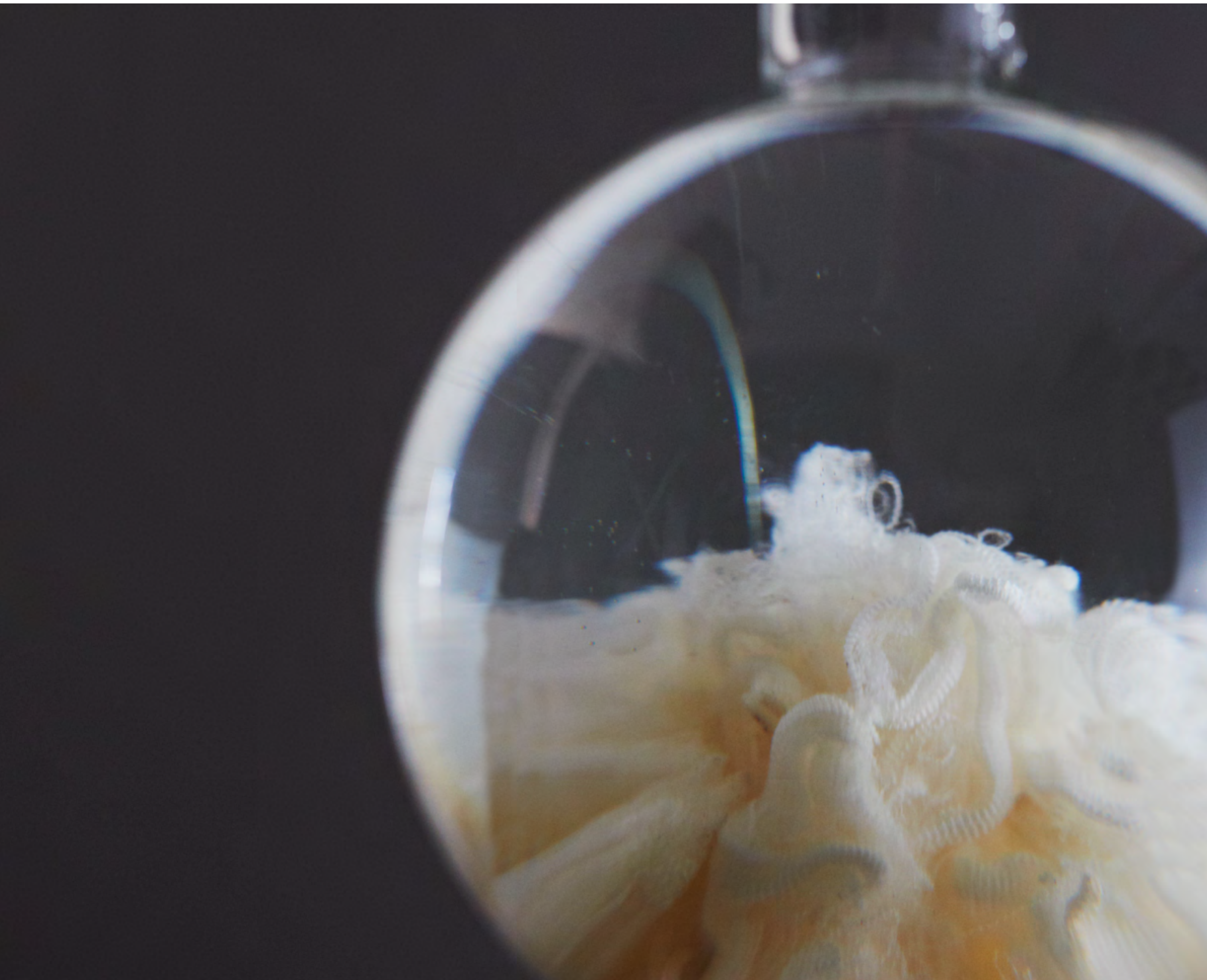
SUGGEST THAT it is easier to understand the processing of wool and the performance of the subsequent products if you understand the behaviour of the wool fibre from the outset.

EXPLAIN THAT this course explores the:

- structure of the fibre
- physics of the fibre, including:
  - the tensile and bending properties of wool
  - why wool stretches more than other fibres
  - why wool is resilient
  - the ageing of wool
- chemistry of the fibre, including:
  - the chemistry of the various fibre components
  - why wool yellows under certain conditions
- implications of the structure, physics and chemistry, including:
  - the setting process
  - relaxation and felting shrinkage
  - how the properties and benefits of wool products are derived from its structure, physics and chemistry.

MODULE 1

WOOL AND OTHER ANIMAL FIBRES



RESOURCES — MODULE 1: WOOL AND OTHER ANIMAL FIBRES

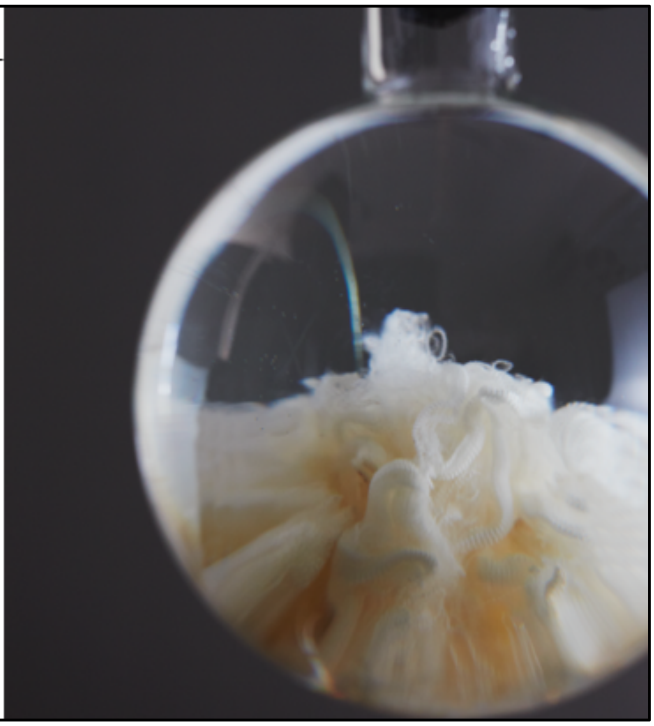
Contained in the *Wool fibre scienc*e Demonstration kit you will find the following resources for use as you deliver **Module 1: Wool and other animal fibres**:

- wool computer bag
- fine wool sample
- broad wool sample
- camel hair sample
- alpaca fibre sample
- cashmere sample
- greasy wool sample.

THE WOOLMARK COMPANY

WOOL FIBRE SCIENCE

Module 1: Wool and other animal fibres



EXPLAIN THAT this first module in *Wool fibre science* will compare wool with other natural and synthetic fibres. It will provide a basic insight into the wool fibre and the animal responsible for producing this renowned natural fibre — the sheep.

***ASK** participants to raise their hands if they are wearing wool.*

If possible, select a participant with their hand raised and explore why they have chosen to wear wool.

If no hands are raised ask participants why they might or might not choose to wear wool.

Limit the discussion to a couple of minutes before proceeding with the following points.

EXPLAIN THAT by the end of this module participants will be able to:

- describe wool in the context of other natural and synthetic fibres and differentiate wool from other animal hair.
- recognise the differences between fibres grown by sheep and those grown by other animals
- nominate the major sheep-growing countries in the world
- recognise there are different types of sheep grown for different purposes and the differences between the types of wool produced by different types of sheep
- describe the key features of wool grown by Merino sheep
- nominate the features of wool that impact on its value.

RESOURCES REQUIRED FOR THIS MODULE

- *wool computer bag*
- *fine wool sample*
- *broad wool sample*
- *camel hair sample*
- *alpaca fibre sample*
- *cashmere sample*
- *greasy wool sample.*

INTRODUCE participants to the *THIS IS WOOL* video by explaining you are going to share with them a short, one-and-a-half-minute video that provides a brief overview of wool, where it comes from, how it grows and some of its applications.

***ASK** participants to list three features of wool mentioned in the video on the associated page of their Participant Guide.*

***PLAY** video (1:20)*

***ASK** a few participants to share some of the features they listed in their notes during the video.*

***ACKNOWLEDGE** responses*

***NOTE:** Suitable responses might include:*

- *Wool is natural*
- *Wool grows on sheep*
- *Wool is biodegradable*
- *Wool is renewable*
- *Wool is used in clothing, interior textiles and other products.*
- *Wool can be used as a pure fibre or blended with other natural fibres or synthetics.*

EXPLAIN THAT wool and other animal fibres have a long history of human use:

- Wool replaced animal skins for clothing from the end of the Stone Age. This meant people didn't have to kill the animal to produce clothes.
- The first recorded use of wool occurred around 4000BC.
- There are records from 3000BC of woollen garments being worn in Britain.
- Pharaohs in Egypt (2000 – 3000BC) were commonly buried in wool garments, which have also been preserved.
- The Mongolians used felted wool to build houses (called Yurts) …. and still do.

WHAT IS WOOL?

Wool is:

- a natural body fibre produced by sheep
- natural, biodegradable, renewable
- used in either:
  - pure form, or
  - blended with other fibres.

12 - **Module 1:** Wool and other animal fibres

EXPLAIN THAT wool is a natural fibre produced by sheep. It is effectively the hair that comes from the sheep's back.

Because wool is a natural fibre, it is biodegradable, easy to renew and offers many benefits to consumers. Some of these benefits will be covered later in the course.

Legally in many countries, the term 'wool' can be used to describe either: pure wool (sheep's wool only), or can used to describe a combination of sheep wool blended with the hair fibres of other animals (e.g. goats, camels, rabbits, yaks, etc.).

However, by definition, wool can only be called 'wool' if it contains at least some of the natural fibre produced by a sheep.

Wool can be used in its pure form or it can also be blended with synthetics (e.g. nylon or acrylics).

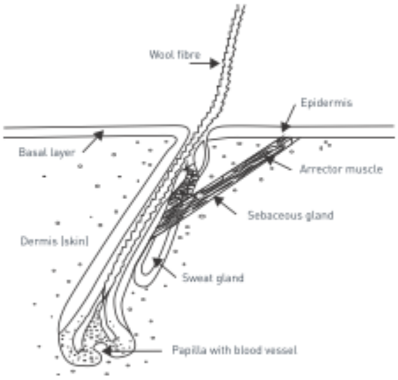
NOTE: The term 'pure wool' cannot be used to describe blended products.

HAND OUT *the sample of greasy wool and ask participants to observe the way it looks, feels and smells. Allow participants to pass the sample around as you continue the lecture.*

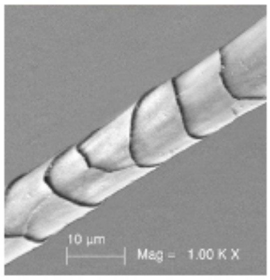
NOTE: *Remember to collect the sample when all participants have finished as it will be required again later in this module.*

THE WOOL FIBRE

Wool fibres grow in tufts called staples.



Source: TWC



The surface of each fibre is formed by microscopic scales.

13 - **Module 1:** Wool and other animal fibres

EXPLAIN THAT wool is chemically and structurally similar to the hair found on other animals, including goats, camels and rabbits. Indeed the human hair, although 2–3 times thicker than wool, is made from the same naturally-occurring proteins.

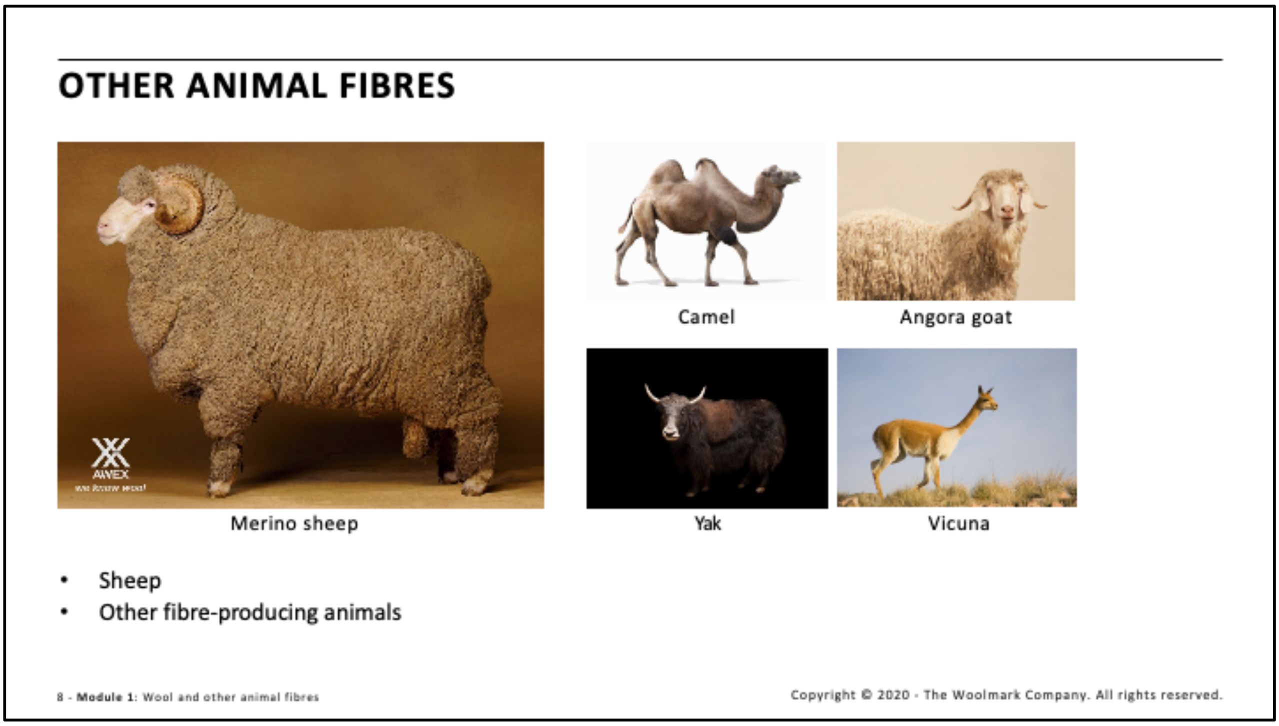
As wool grows in the follicle, it is covered with a natural greasy substance. This substance is removed by scouring before any further processing is carried out. This natural wax can be recovered during scouring to produce lanolin, which is used in many cosmetics and soaps.

The procedures to remove and recover wool wax are covered in another Wool Science, Technology and Design Education Program course.

EXPLAIN THAT wool fibres grows in tufts, called 'staples', as illustrated on the slide. As shown in first image on the slide, each fibre also grows in a wave pattern known as 'crimp'. The finer the wool, the more obvious and more frequent the crimp. The crimp helps trap still air between the fibres, providing an effective insulating layer (warm in winter and cool in summer).

NOTE: Some wools have crimp and other do not. Crimp will be discussed more in the next module.

In addition to crimp, another important feature of the wool fibre are the scales that occur along the fibre surface. These scales have evolved to help prevent dirt and water from reaching the sheep's skin and are part of the reason why wool is easy to keep clean. The scale structure on the surface of the fibre is also important in making felts and traditional woollen cloths. Much more about the nature of felting will be discovered in this course and the subject of scales will be discussed more in the next module and several times throughout this course.



EXPLAIN THAT the list of animals that produce hair used as a textile fibre is quite long and includes:

- Goats — cashmere, mohair and angora are all fibres produced by different breeds of goat.
- Rabbits — Although angora is a fibre produced by angora goats, it is also a fibre produced by angora rabbits.
- Yaks — Yaks produce two types of fibre: guard and down. Only the down is used in textile applications.
- Alpaca, llama, guanaco, vicuna and other camelids also produce fibre used in textiles.
- Possum — Possum hair is sometimes blended with other animal fibres.
- Human hair has even been used for textiles, but is much coarser (thicker) than wool.

***HAND OUT** samples of:*

- *fine wool*
- *broad wool*
- *camel hair*
- *alpaca fibre*
- *cashmere.*

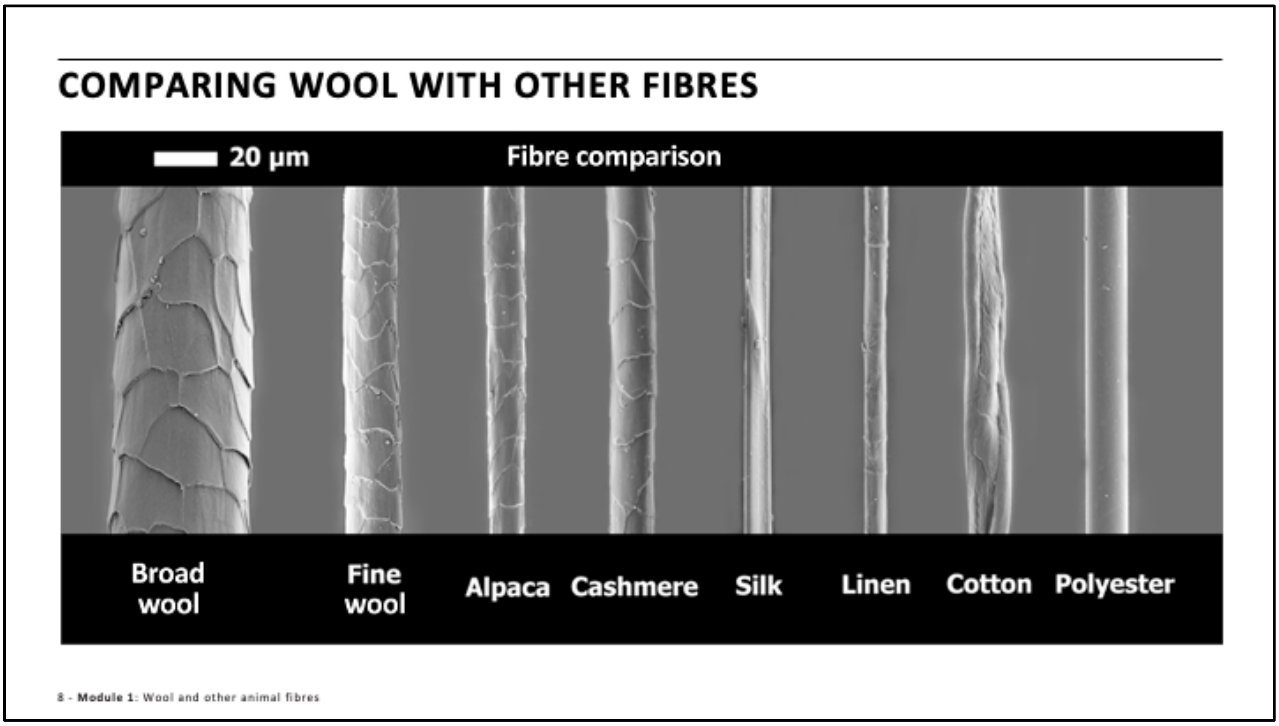
While participants are exploring the fibre samples, explain that some animals (e.g. cashmere goats and yaks) produce two types of hair:

- *down — the fine hair next to the animal's skin*
- *guard hair — the coarser hair on the outer surface of the animal's fleece.*

EXPLAIN THAT wool from sheep is generally categorised by its fineness (or thickness), which is measured in 'microns' (micrometers — µm). One micron equates to one millionth of a metre.

The finer the wool, the more expensive it is. This is because fine wool is softer and more comfortable to wear. The value of wool is discussed later in this module.

NOTE: Remember to collect the samples when all participants have finished as they will be required again later in this module.



EXPLAIN THAT this slide illustrates the differences between a range of natural and synthetic fibres.

ENCOURAGE participants to note the different thickness between the broad and fine wool fibres shown on the slide.

ASK *students to record their estimates of the fibre diameter of each fibre in their Participant Guide using the 20µm scale at the top of the image.*

SELECT *a few students to share their estimations with the group.*

ACKNOWLEDGE *responses.*

NOTE that the slide also illustrates that only animal hairs have scales (broad wool, fine wool, alpaca and cashmere from goats). Also note how the scales on the surface of the various animal hair fibres have different patterns. Scales are important for protection, felting behaviour and the handle of consumer products. They provide a durable waterproof surface.

EXPLAIN THAT the topic of scales will be covered at several points in this course.

NOTE THAT the silk fibre, which is also a natural animal fibre, does not have scales as it is not a hair, but is produced by silkworm larvae.

EXPLAIN THAT linen and cotton are plant fibres primarily made of cellulose, but are quite different physically:

- Cotton has a twisted ribbon structure.
- Linen is a more tubular structure.

INTRODUCE synthetic fibres by referring students to the image of polyester on the slide, while explaining that synthetic fibres tend to be cylinders, except where the manufacturers deliberately make them different shapes.

EXPLAIN THAT synthetic fibres can come in a range of cross-sectional shapes (e.g. lobar, hollow, core sheath, etc.).

Manufacturers can change the shape of synthetic fibres to meet a range of purposes (e.g. apparel, filling, insulation). Woolgrowers are unable to influence or change the cross-sectional shape of wool fibres produced by their sheep.

__PLAY__ the one-minute video as you explain that the footage shown was taken on an Australian sheep property (farm) using a drone.

EXPLAIN THAT the English word for describing a group of sheep is ‘flock’. In Australia the word ‘flock’ is used to describe all the sheep on a single property, while a group of sheep in a single paddock (field) is often called a ‘mob’.

EXPLAIN THAT sheep properties in Australia can vary widely in size depending on the location and rainfall. In Australia sheep are grown in high and low rainfall (semi-desert) regions.

The stocking rates (number of sheep per hectare) also vary widely depending on the type of farming, which is mostly driven by rainfall and the availability of feed (edible plant material, such as grass and legumes, such as clover).

__BEFORE REVEALING__ the next slide ask participants to name any sheep breeds they know of.

__RECORD__ responses on the flipchart or whiteboard.

REVEAL SLIDE

EXPLAIN THAT not all wool is the same. There are more than 1000 breeds of sheep around the world, which produce different types of wool, used for various purposes. This slide only shows a few of these breeds.

The wool from different breeds of sheep varies across a range of characteristics including fineness (fibre diameter), length of the fibre, amount of crimp and colour.

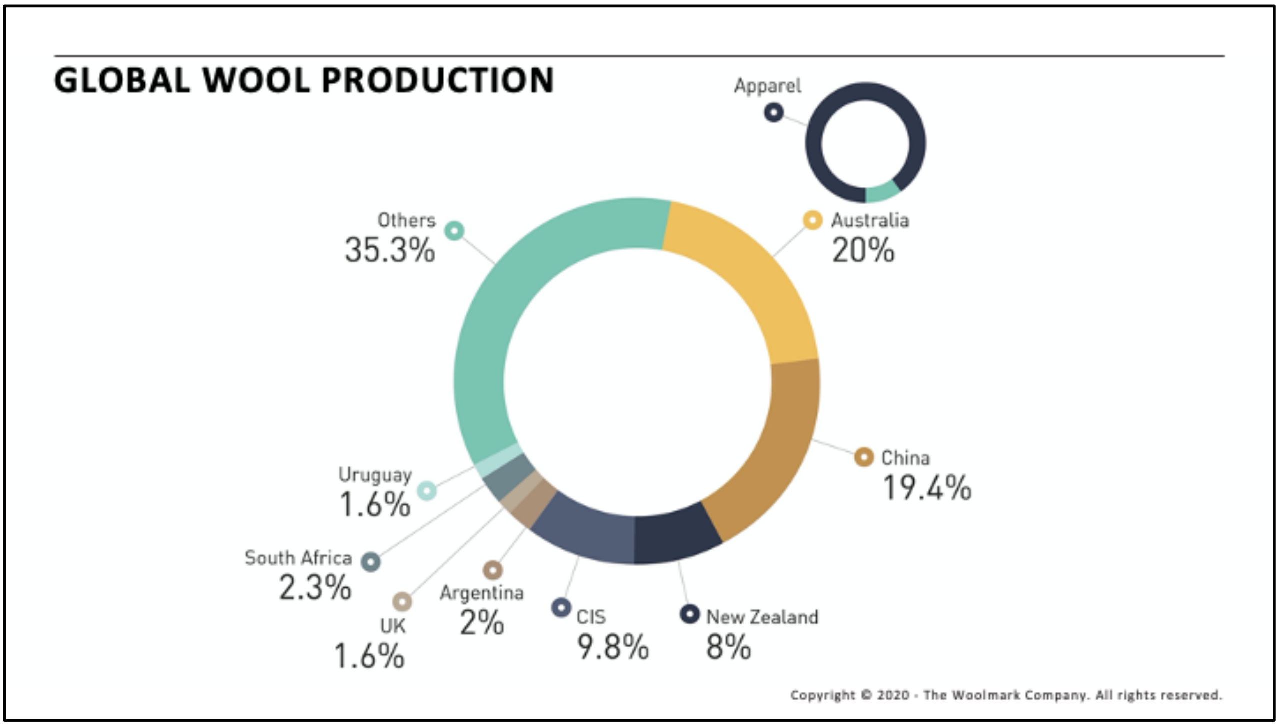
Some sheep are primarily bred for meat and others primarily for wool. Some sheep are also used to produce milk.

- Sheep primarily bred for meat (e.g. Poll Dorset and Polwarth) usually produce a broader wool, which can be used in carpets, rugs, blankets and upholstery.
- Sheep primarily bred for their wool (e.g. Merino) usually produce a finer, (thinner) wool, which is softer and generally more expensive. Fine wool is usually used to make garments such as suits, jumpers, skirts and scarves.

In addition to the many pure breeds, the crossbreeding of sheep (mating a sheep of one breed to a sheep of another breed) is popular to produce a dual-purpose animal, which can be used to produce both wool and meat.

SUGGEST THAT if participants want to explore in greater detail the different sheep breeds, their origins, purpose and the characteristics of their wool, they can download Sheep Breed Compendium App by AWEX:
Android:
https://play.google.com/store/apps/details?id=digibale.com.sheepbreed&hl=en

Apple: https://itunes.apple.com/au/app/sheep-breed-compendium-by/id1092317391?mt=8



EXPLAIN THAT Australia and China are the biggest global producers of clean wool, followed by New Zealand, South Africa, UK, Argentina and the USA.

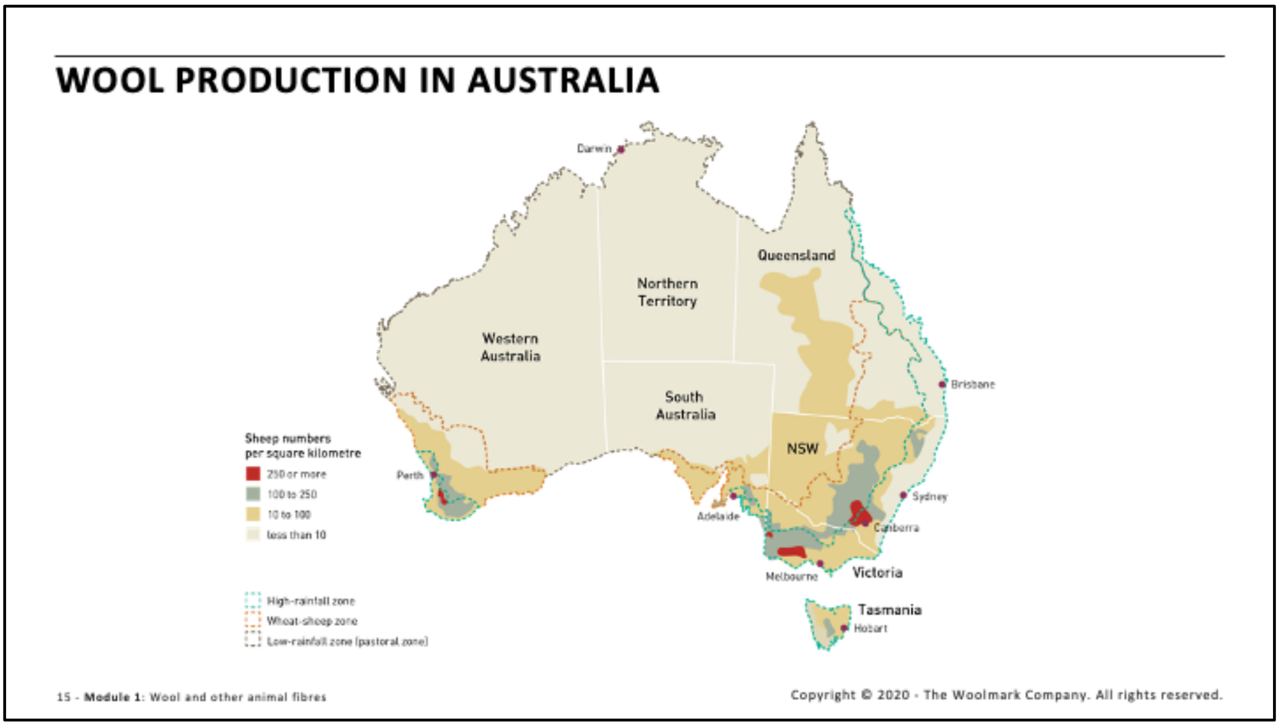
The predominant breed of sheep in Australia is the Merino. More than 70 per cent of Australian sheep are Merinos and there are estimated to be more than 70 million Merinos cared for by more than 50,000 woolgrowers across the country.

The Merino breed originally came to Australia from Turkey and central Spain in 1797, via South Africa. Captain John Macarthur, the Reverend Samuel Marsden and Eliza Forlonge were responsible for seeding an industry that became the mainstay of the Australian economy for many years.

EXPLAIN THAT wool produced from Merino sheep is finer than wool produced from other breeds.

Australian Merino sheep produce ultrafine to medium micron wool used for knitwear, high-quality suits and fashionwear. Merino wool is renowned for its fineness and softness, which makes it perfect for apparel. Fashion houses all around the world value Australian Merino wool.

NOTE THAT as outlined on the slide, Australia is the largest producer of fine apparel wool.



REFER participants to the map on the slide as you explain that sheep production is carried out in most states across Australia.

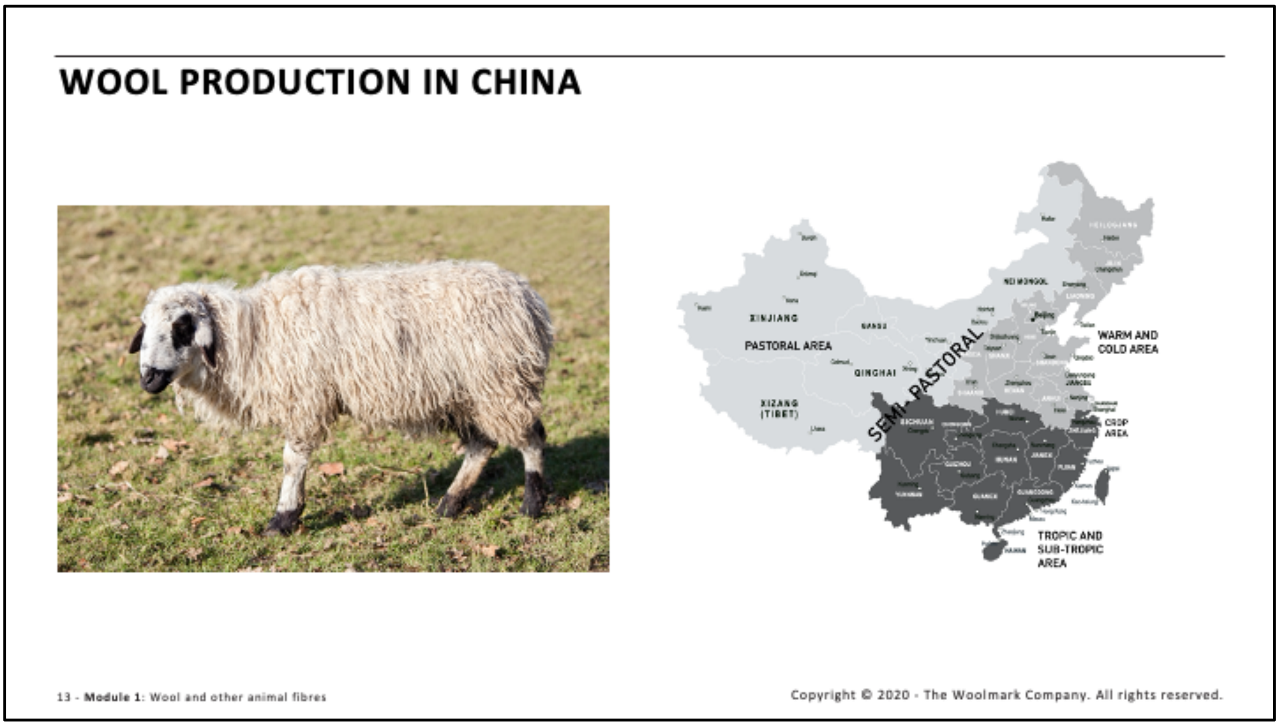
EXPLAIN THAT in many areas mixed farming (livestock and crops) is practiced and sheep are grown for both meat and wool production.

Most of Australia's wool is produced in New South Wales (NSW).

PROVIDE an example of wool production levels by explaining that during 2018/19 total greasy wool production was 317,763 million kilograms (Mkg) with the following breakdown by state:

- New South Wales: 105 million kilograms
- Victoria: 77.8 million kilograms
- Western Australia: 65.5 million kilograms
- South Australia: 49.9 million kilograms
- Tasmania: 10.6 million kilograms
- Queensland: 8.4 million kilograms

ACKNOWLEDGE the source of these statistics as the Australian Wool Exchange (AWEX).



REMIND participants that China also has a large wool growing industry — one of the largest in the world. However China does not produce a significant amount of fine-quality wool as Merino sheep have not adapted to the harsh conditions of the Chinese pastoral zones.

REFER participants to the slide, which shows a picture of Hu sheep — one of the breeds developed in China.

INDICATE THAT most of the sheep production carried out in China occurs in the north-west regions of the country.

EXPLAIN THAT although China produces wool, most of China's sheep are managed for meat production.

WOOL PRODUCTION IN NEW ZEALAND

Corriedale

Romney

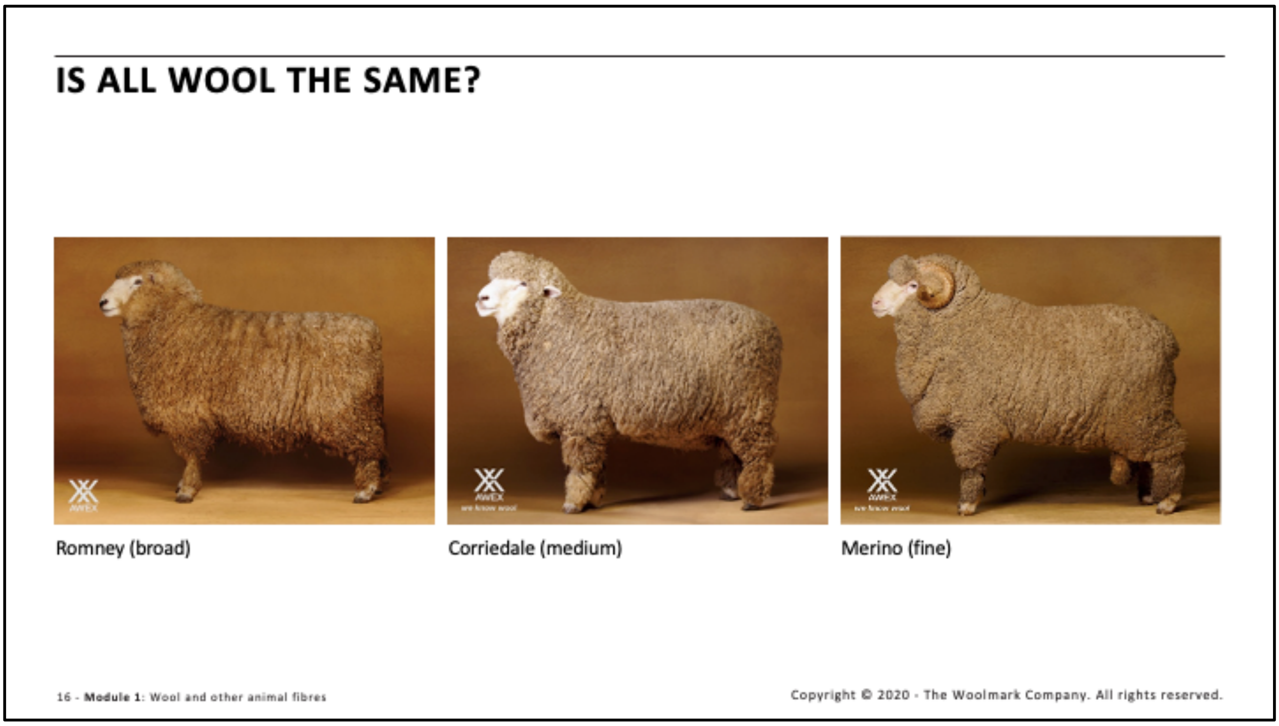
14 - **Module 1:** Wool and other animal fibres

EXPLAIN THAT along with Australia and China, New Zealand also a significant wool production industry.

While most of Australia's sheep are Merinos, New Zealand sheep producers predominantly run dual-purpose breeds such as Corriedale and Romney.

EXPLAIN THAT the wool produced by these breeds is much broader than that produced by the Australian Merino. There is a growing fine-wool Merino industry in New Zealand.

Australia produces predominantly fine Merino wool (for clothing) New Zealand produces predominantly broad wool (for carpets).



REMIND participants that not all wool is the same.

HAND OUT *the samples of fine and broad wool again.*

EXPLAIN THAT *the two samples come from two different breeds of sheep.*

As participants explore the samples, reinforce that many breeds of sheep around the world produce different types of wool used for various purposes.

EXPLAIN THAT wool from different sheep breeds is divided into three main categories (broad, medium and fine) based on the diameter (fineness) of the wool fibre, measured in microns.

Broad (>29µm)

- Breeds such as the Romney produce long, medium-lustre wool, which is particularly useful for carpets and furnishings because of its strength and durability.

Medium (23– 29µm)

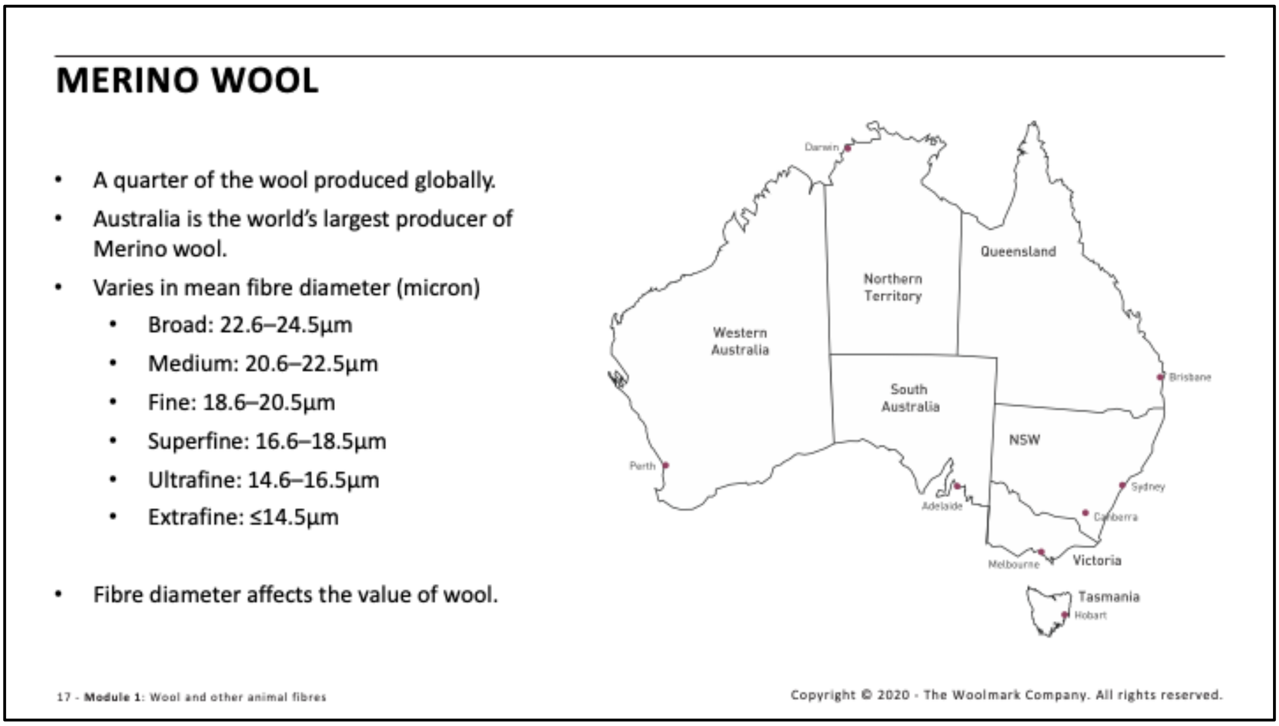
- Breeds such as the Corriedale produce medium wools used in a variety of woven apparel cloths, knitting yarns and furnishings.
- A wide range of medium wools that have been produced by crossing one breed of sheep with another.

Fine (< 23µm)

- Although some non-Merino breeds produce wool in the range of 23µm, wool with the finest micron comes from Merino sheep.

EXPLAIN THAT within the wool industry, the terms broad, medium and fine can be used 'loosely'. There are some differences in the application of these terms with different sheep breeds and crossbreeds. However, the ranges shown here represent a loose consensus within the global wool-growing industry.

NOTE: *Remember to collect the samples at the completion of the lecture.*



EXPLAIN THAT you are now going to focus specifically on Merino wool.

EXPLAIN THAT Australian Merino sheep provide one quarter of all the wool produced in the world and Australia is the largest producer of Merino wool.

REITERATE THAT during 2018/19 Australian woolgrowers produced 317,763 million kilograms (Mkg) of greasy wool.

EXPLAIN THAT in addition to the three broad categories of wool just discussed, Australian Merino wool has a grading system that further categorises this premium-grade fibre:

- Broad Merino has a mean fibre diameter of 22.6–24.5 µm (around 17% of the Australian wool clip).
- Medium Merino is slightly finer at 20.6–22.5µm (around 23% of the Australian wool clip
- Fine Merino represents the biggest amount of Australian wool (18.6–20.5µm) at around one third of the Australian wool clip
- Superfine Merino is between 16.6–18.5µm
- Ultrafine Merino is between 14.6–16.5µm
- Extrafine Merino is ≤14.5µm.

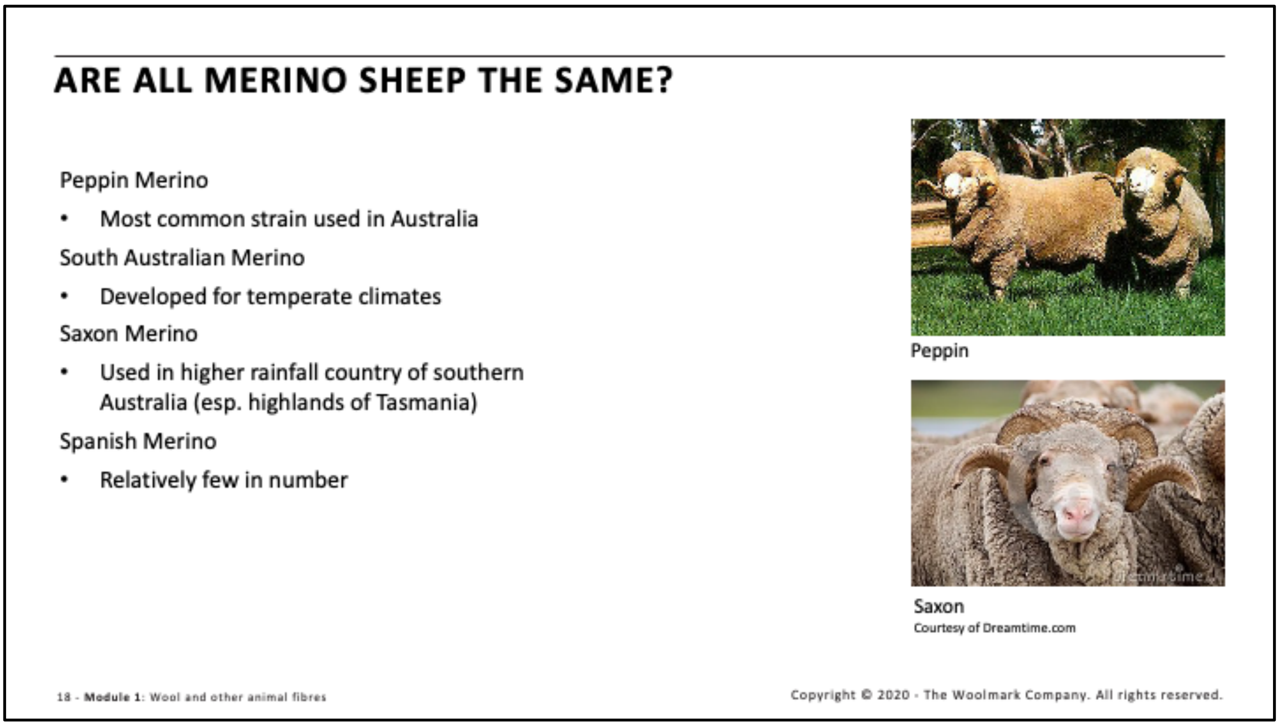
EXPLAIN THAT superfine, ultrafine and extrafine combined represent around 23% of the Australian wool clip.

REFER participants to the map on the slide as you explain that the grade of wool tends to vary by region, the finest wool comes from NSW, western Victoria and Tasmania, with broader wools coming from NSW, SA and WA.

INDICATE THAT there is no 'legal definition' of 'Merino' for labelling products containing Merino wool. The best definition for Merino wool is 'wool from a Merino sheep'.

EXPLAIN THAT after the wool (fleece) has been shorn (harvested) it is difficult to tell its exact origin, especially for wool in the range 21-25µm, which can also be produced by non-Merino breeds (e.g. Corriedale).

POINT OUT the terms superfine and ultrafine are defined by industry practice rather than being legal terms and there is still some variation in usage of these terms.



EXPLAIN THAT as well as different sheep breeds varying in their characteristics, not all Merino sheep are the same.

EXPLAIN THAT from the original flock of Merino sheep brought to Australia during the late 1700s, four main strains of Merino have been bred.

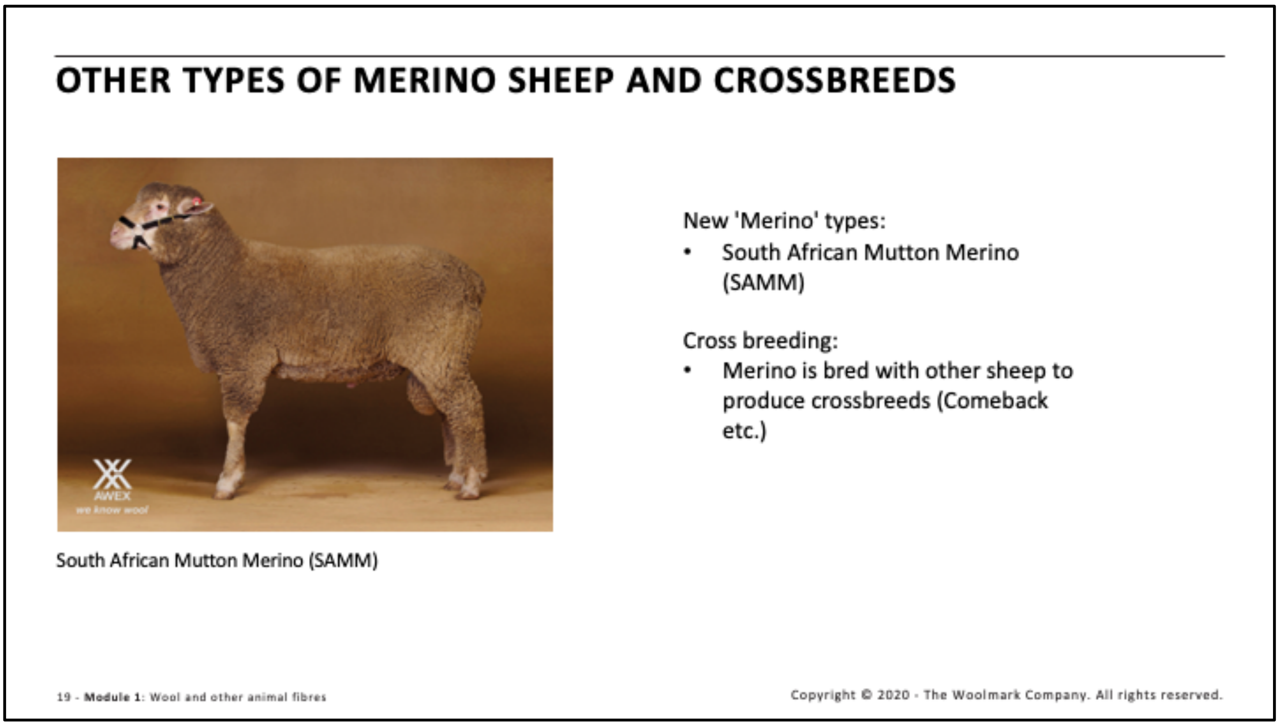
OUTLINE the main strains of Merino sheep as per the notes below:

Peppin Merino
- Adaptable to a variety of conditions
- Most common strain used in Australia
- Cuts up to 10kg per year

South Australian Merino
- Developed for temperate climates
- Physically the largest strain cutting heaviest fleeces
- Grows broad Merino wool

Saxon Merino
- Used in higher rainfall country of southern Australia (esp. highlands of Tasmania)
- Physically the smallest of the Merino types, cutting 3–6kg.
- Without peer in the quality of wool produced (diameter to 11.5µm with good colour)
- Desired for its good bulk and softness

Spanish Merino
- Relatively few in number



EXPLAIN THAT in addition to the Australian Merino breeds covered in the previous slide, there are also some new 'Merino' types, which have been developed by controlled breeding over the past 20–30 years. One such example is the South African Mutton Merino (SAMM) shown on the slide.

EXPLAIN THAT the objective of this breeding strategy is to develop dual-purpose Merinos that produce high-quality and high-quality meat.

INDICATE THAT Merinos also can be mated with other sheep breeds (cross breeding) to produce dual-purpose sheep.

Cross breeding is common and generally carried out by mating non-Merino rams (males) with Merino ewes (females). The aim of cross breeding is usually to produce lambs that still produce wool (although not so fine as pure-bred Merinos), but have better meat-producing characteristics (i.e. produce more meat in a shorter growing period).

REMIND participants there is no 'legal definition' of 'Merino' for labelling products containing Merino wool even though the Merino is a well recognised breed of sheep, with various genetic lines.

EXPLAIN THAT the best definition for Merino wool is 'wool from a Merino sheep'.

REINFORCE THAT after the wool (fleece) has been shorn (harvested) it is difficult to tell its exact origin, especially for wool in the range 21-25µm, which can also be produced by non-Merino breeds (e.g. Corriedale).

HOW IS WOOL VALUED?

- Type (fleece vs pieces)
- Fibre diameter (micron)
- Yield (clean wool content)
- Vegetable matter:
  - type
  - quantity
- Staple length (mm)
- Staple strength:
  - breaking load (N/tex)
  - position of break
- Clean colour
- Pesticide residues

20 - **Module 1:** Wool and other animal fibres

EXPLAIN THAT after it is harvested, wool is valued based on its suitability for specific end uses, as well as the fundamentals of the world wool market.

The price of wool can vary enormously (from AU$500 a kilogram to AU$1 a kilogram). The value of wool depends on the following criteria:

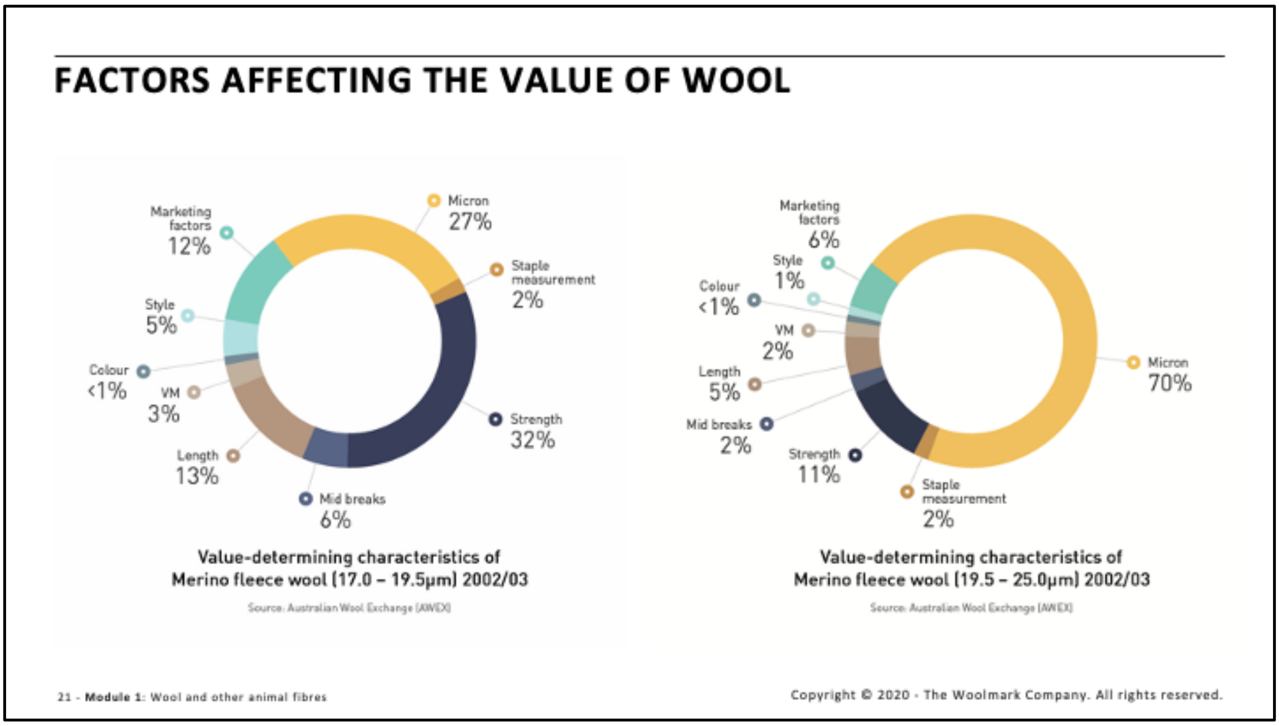
- **Type (fleece or pieces)** — The fleece is the wool from the main body of the sheep, which is skirted to remove any dirty pieces of wool around the legs and belly. Fleece wool has a higher value than pieces of wool.
- **Fibre diameter (micron)** — The lower the diameter, the higher the value/price.
- **Yield (clean wool content)** — The higher the yield, the higher the value.
- **Vegetable matter** — Vegetable matter (plant material) in wool is a disadvantage, as its removal during processing can be costly.
  - Type — some types of vegetable matter (e.g. burrs) are harder to remove than others
  - Quantity — the more vegetable matter, the lower the value of wool.
- **Staple length (mm)** — Both short wools and overly long wool are discounted.
- **Staple strength**:
  - Breaking load (N/tex) — The stronger the staple, the higher the value.
  - Position of break — Staples can break in the base, middle or tip region. Staple with a low mid-break are higher in value, as they give a longer average length in the top
- **Clean colour** — Brighter wools have a wider range of uses and often receive a higher price.
- **Pesticide residues** — The presence of excessive levels of pesticide residues can reduce the value. Woolgrowers manage pesticides carefully to ensure residual levels are environmentally acceptable.

ASK *participants if they know or can guess which criteria list on the slide is the main determinant of value.*

ALLOW *participants to consider their answer and to respond.*

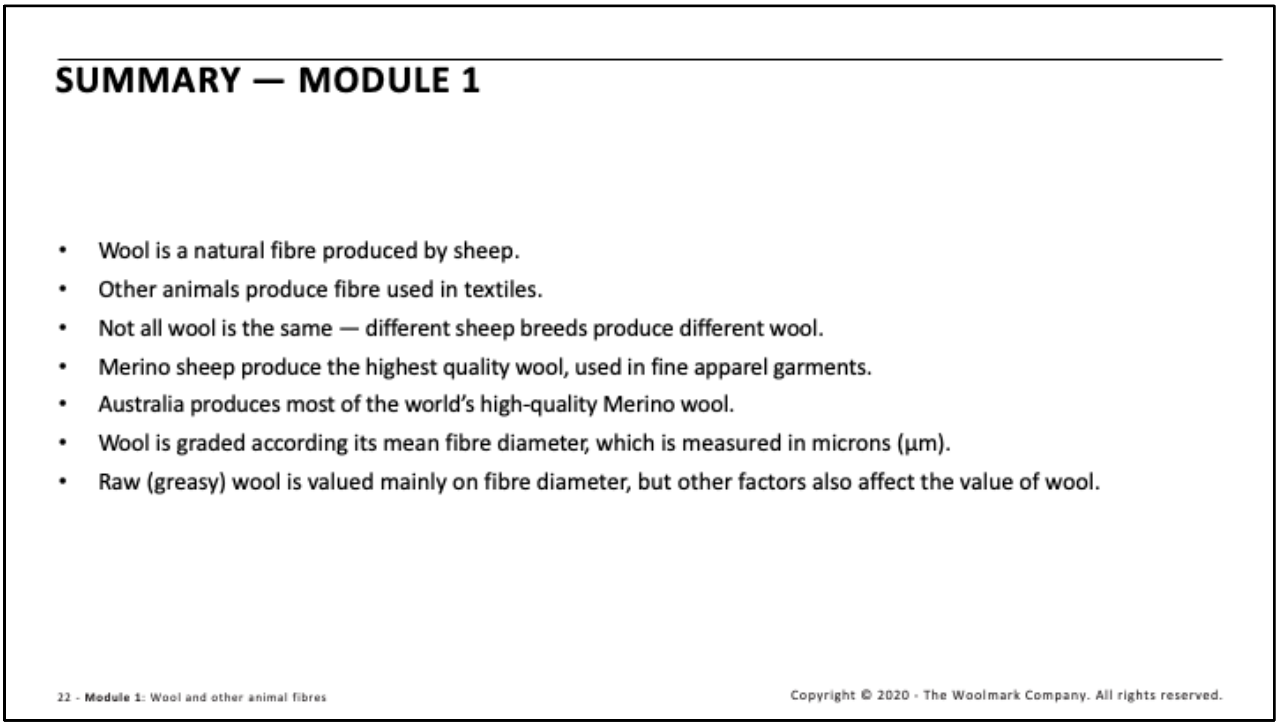
ANSWER: *Fibre diameter is the main determinant of the price of wool.*

REMIND *participants the answer is included in their notes before proceeding to the next slide.*



EXPLAIN THAT the importance of wool properties in determining price varies with the type of wool and from year to year. For example:

- For fine and superfine Merino wools, strength of the fibre can be as important in determining price as mean (average) fibre diameter.
- For medium and broad Merino wools, the mean fibre diameter is clearly the dominant property determining price.



SUMMARISE the module by reinforcing the following points:

Wool is a natural fibre produced by sheep.

Other animal fibres are also used in textiles.

Not all wool has the same characteristics — different sheep breeds produced different types of wool. Merino sheep produce the finest, high-quality wool used in fine apparel garments.

Australia produces most of the worlds' high-quality Merino wool.

Wool is graded according to its fineness (mean fibre diameter), measured in micrometres (microns).

Raw (greasy) wool is valued mainly on fibre diameter, but other factors also affect the value of wool.

***ASK** participants if they have any questions about the content covered in this module.*

***ALLOW** time for questions and discussion before proceeding to the final slide and closing the lecture.*

INFORM participants of the time and location for the next lecture — *Module 2 The structure of wool fibres* — and encourage them to read through the relevant notes in their Participant Guides before attending the lecture.

ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in today's lecture.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

MODULE 2

THE STRUCTURE OF WOOL FIBRES

RESOURCES — MODULE 2: THE STRUCTURE OF WOOL FIBRES

Contained in the *Wool fibre science* Demonstration kit you will find the following resources for use as you deliver **Module 2: The structure of wool fibres**:

- 3-D model of the wool fibre
- delipidised wool fabric
- untreated wool fabric.

WELCOME participants to Module 2 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The structure of wool fibres*.

EXPLAIN THAT this module focuses on the structure of wool fibres, emphasising the nature of the various components of the wool fibre and:

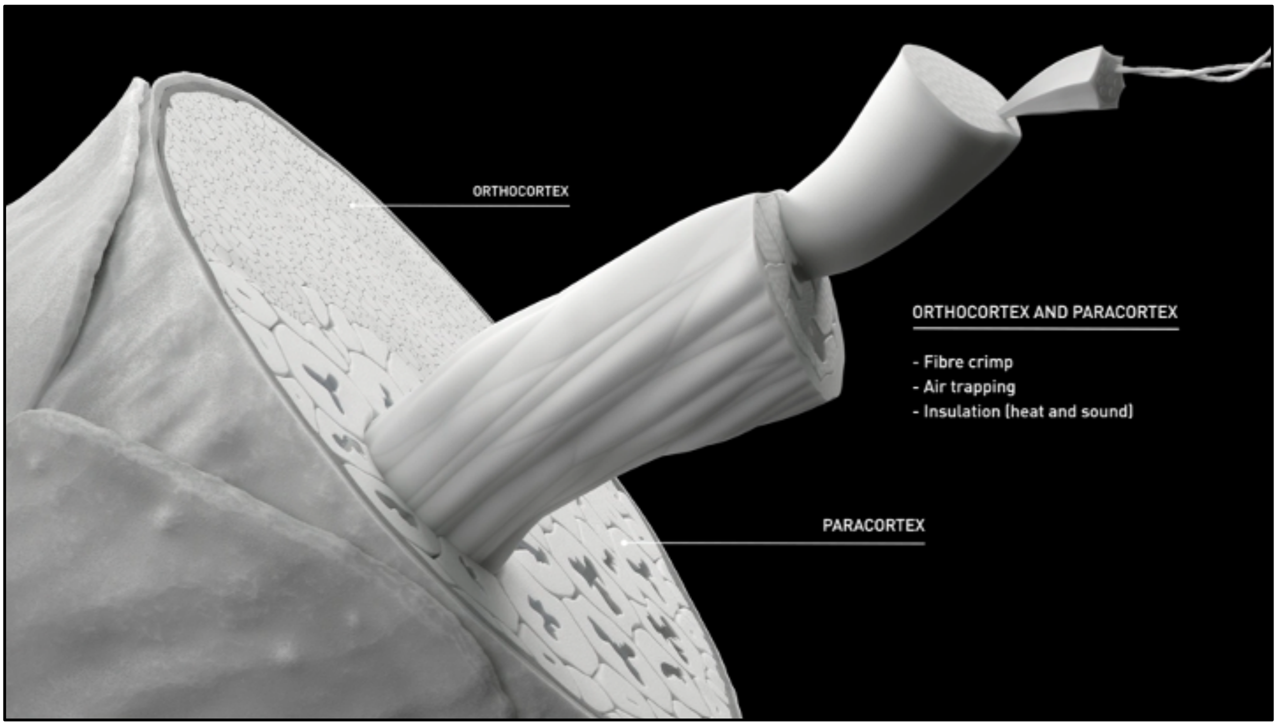
- what the components are made of
- what these components do
- how these components can be modified to improve or change various aspects of the performance of wool.

INFORM participants that by the end of this module they will be able to:

- name the major features of the wool fibre
- describe the various layers of the cuticle cells and their characteristics
- describe the types of cortical cells and their characteristics
- describe the impact of the distribution of the cortical cells
- describe, in general terms, the components of the cortical cells
- describe the cell membrane complex and its role
- describe the brick, mortar and tile model of the wool fibre.

RESOURCES REQUIRED FOR THIS MODULE

- *3-D model of the wool fibre*
- *delipidised wool fabric*
- *untreated wool fabric.*



INTRODUCE the video produced by The Woolmark Company and explain that it provides a useful overview of the structure of wool and the benefits associated with it.

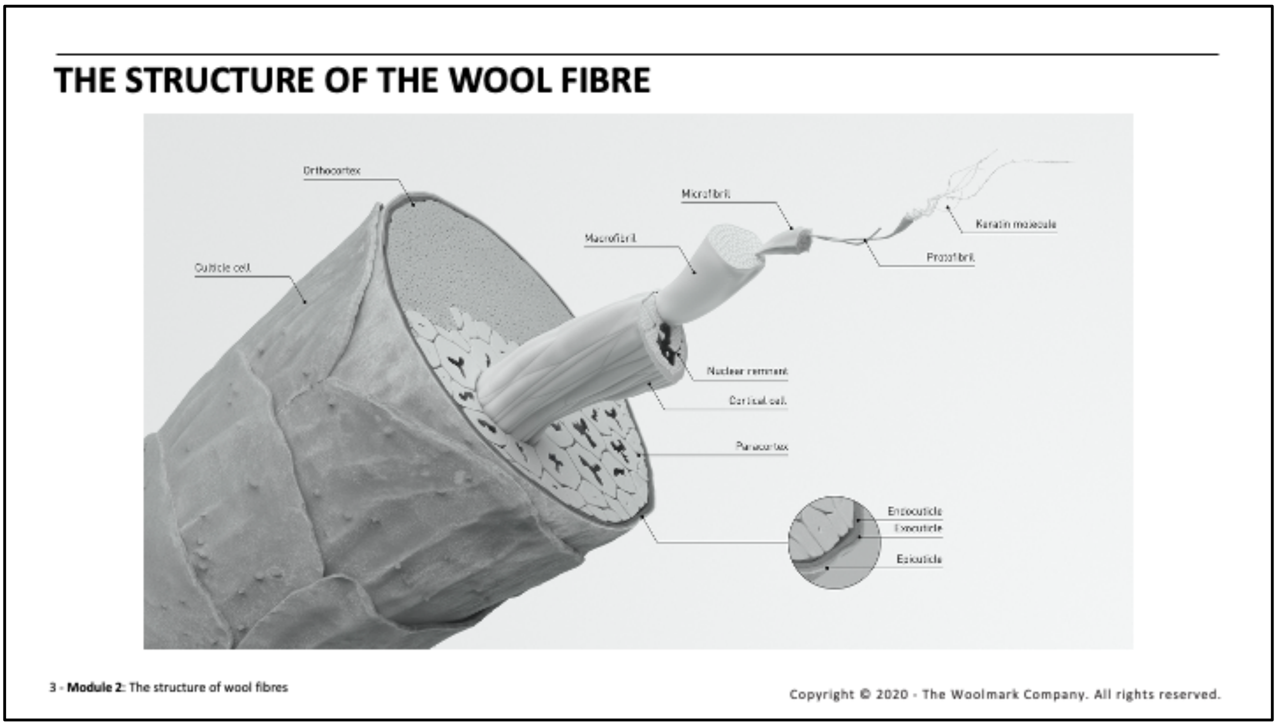
PLAY *video (50 seconds)*

ASK *participants to recall at least two structural features they saw in the video and their related properties.*

LIST *participant responses on the flipchart or whiteboard. Allow three minutes for group discussion.*

REPLAY *the video to reinforce learning and fill in any gaps on the flipchart or whiteboard as the video plays, asking participants to call out the missing names as they appear in the video.*

NOTE: *If participants are reluctant to call out the names from the video you can say these out loud as you list them on the flipchart or whiteboard.*



***HAND OUT** the 3-D model of the wool fibre to the group and allow them to explore the fibre as you explain that the wool fibre has a highly complex structure involving many components that differ both physically and chemically.*

***NOTE** the following points as participants explore the 3-D model:*

- *The scales on the outside are called cuticle cells.*
- *The cells on the inside are called cortical cells.*
- *The cortical and cuticle cells are separated by the cell membrane complex.*
- *The cortical cells are made up of macrofibrils and microfibrils (sometimes called 'intermediate filaments').*
- *The material binding these fibrils is often called the 'matrix' material.*
- *The macrofibril and microfibril cells have regions of low crystallinity and high crystallinity.*
- *The matrix material has low crystallinity and contains the high-sulphur proteins.*
- *The most basic component of the cells is the protein molecule α-helix, which forms the crystalline regions of the fibre.*

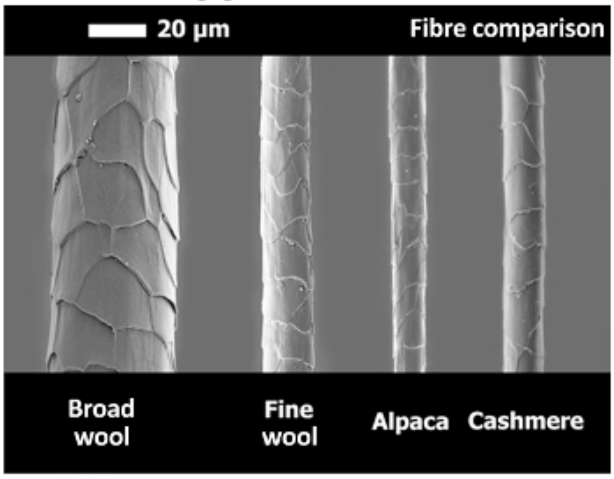
EXPLAIN THAT while the fibre may be 15–45µm in width and several centimetres (cm) in length, the smallest component may be as tiny as 1 nanometre (nm) in width and several nanometres long.

***COLLECT** the 3-D model or the wool fibre as you explain that many broad wool fibres (>35µm) have additional structures within the fibre, including:*

- *the medulla — a central core of cells containing air-filled space, which has evolved to improve the insulation value of the fleece, and*
- *nuclear remnants.*

COMPARISON WITH OTHER ANIMAL FIBRES

Root end of fibre emerging from the skin



Tip end of fibre

Note the scales on the surface of animal fibres, designed to protect the animal from dirt or other materials, which could irritate the skin.

4 - **Module 2:** The structure of wool fibres

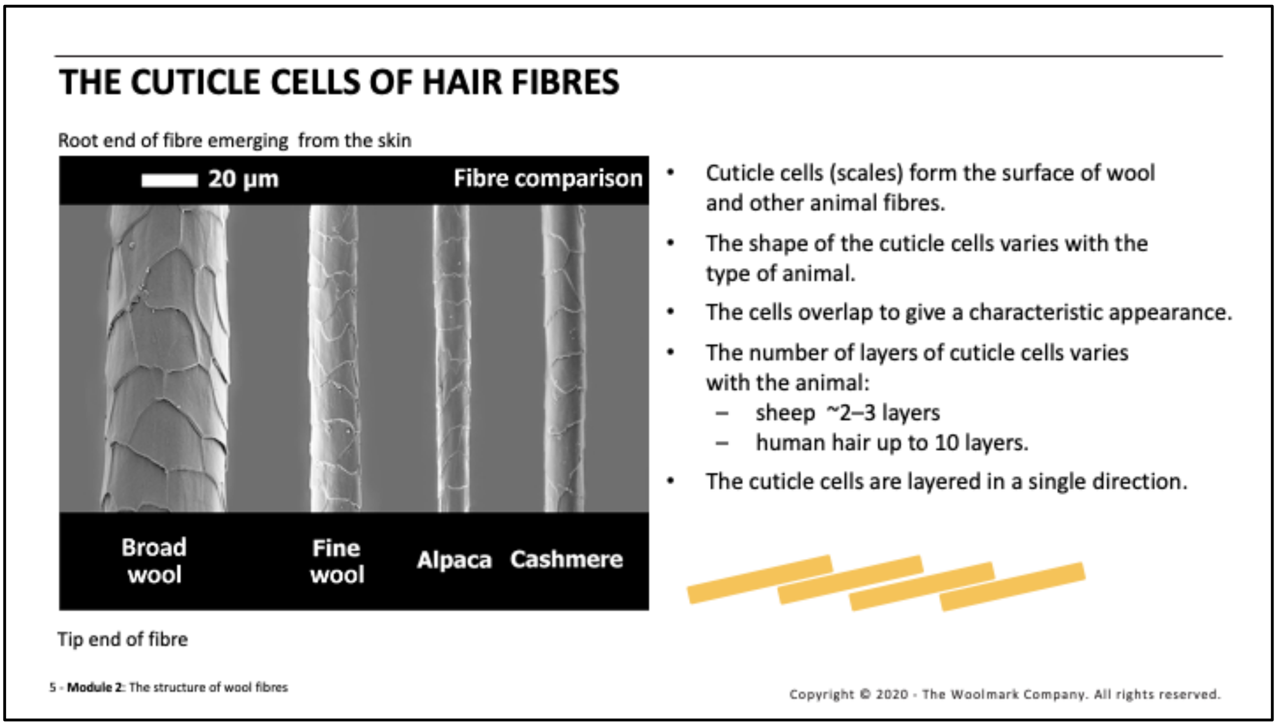
EXPLAIN THAT the image on the slide illustrates how wool fibres differ to other animal fibres.

ENCOURAGE participants to note that the fibres from different animals have different scale patterns.

REITERATE THAT the scales are important for protection, felting behaviour and handle of wool products.

Scales have a durable waterproof surface.

POINT OUT that wool fibres not only have a distinctive surface; they also differ in their thickness. Note the difference in diameter between the broad wool and fine wool shown in the slide.



EXPLAIN THAT the cuticle cells, or scales, form the surface of wool fibres (as well as other animal fibres).

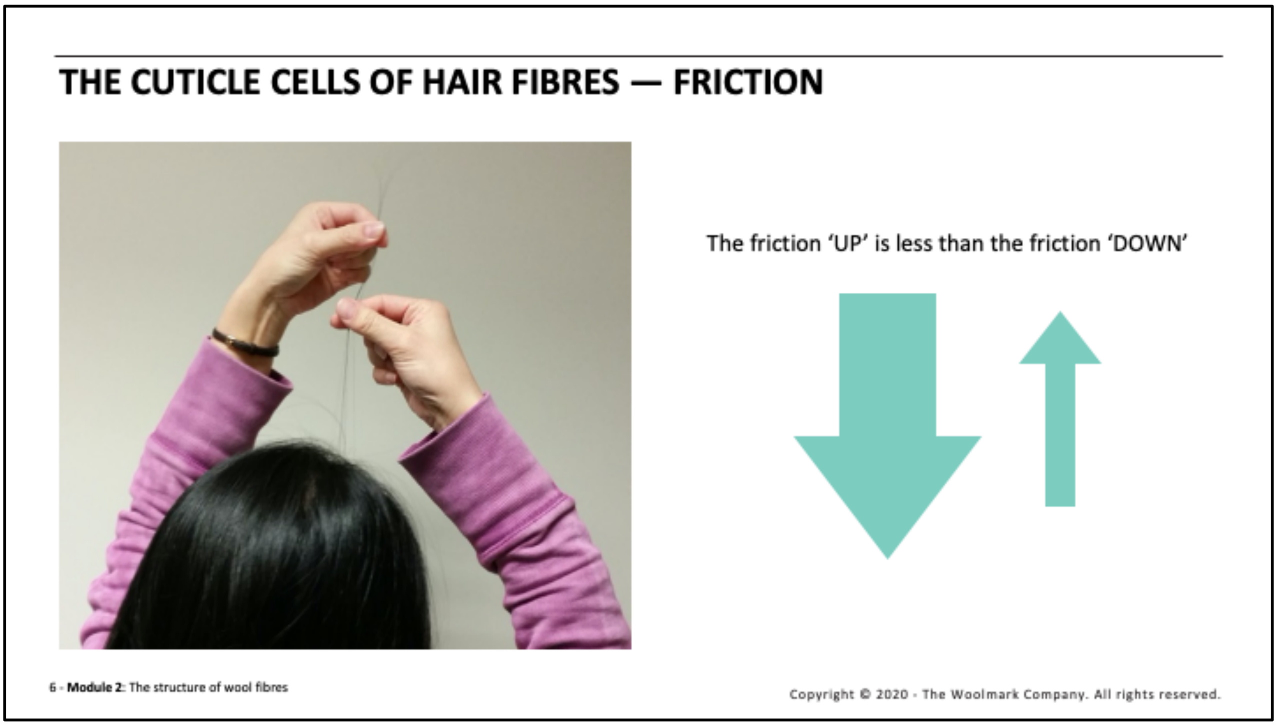
The shape of the cuticle cells varies with the type of animal. For example, the shape and thickness of cashmere cells is different to those of wool and alpaca fibre.

The number of layers of cuticle cells on the surface of the fibre also varies with the type of animal:

- sheep: ~2-3 layers
- human hair: up to 10 layers.

EXPLAIN THAT although the cuticle is the outermost layer of the hair, it does not give the hair its colour. Cuticle cells are clear because they contain no melanin.

The cuticle cells overlap and are layered in a single direction. This arrangement gives animal fibres their unusual frictional properties.



INFORM participants it is possible to feel the scales on the surface of human hair fibres.

***DEMONSTRATE** the following process as you encourage participants to carry out the actions on their own hair:*

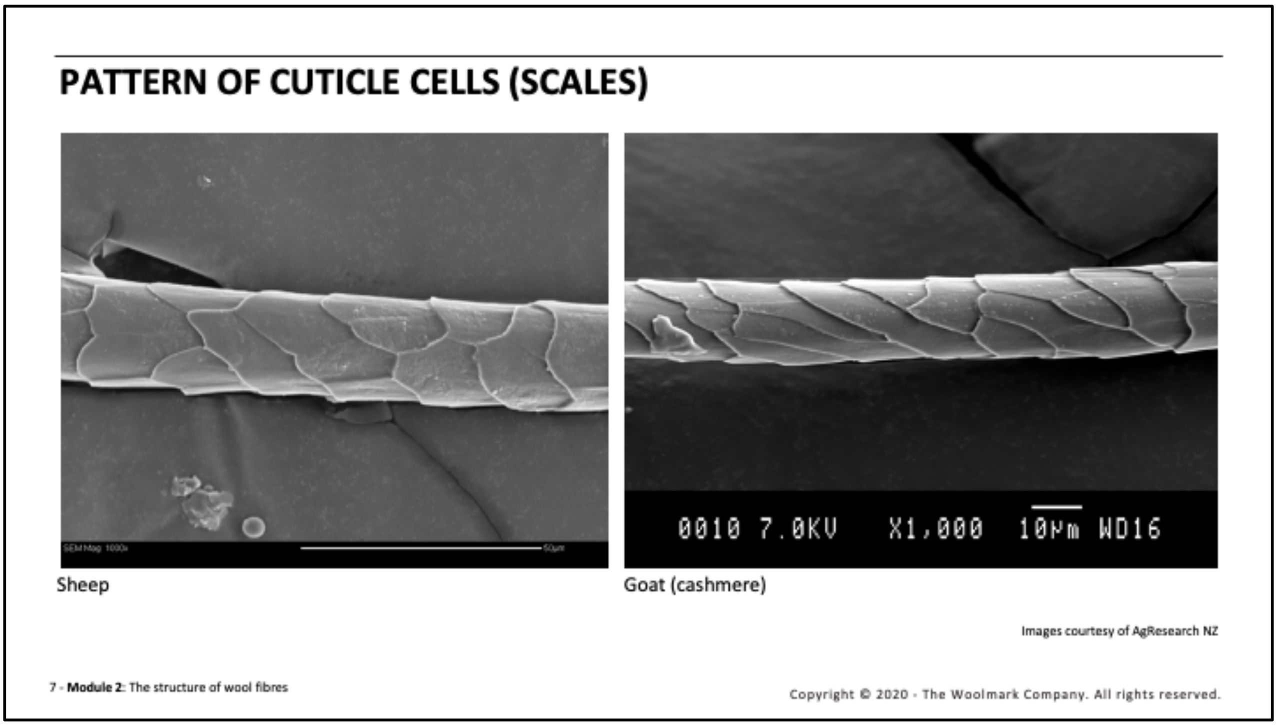
Take one or two strands of hair from your head and stroke the hair up and down with your fingers.

***ASK** participants to note the resistance is greater when the fibre is stroked towards its base (your scalp), than when the fibre is stroked towards its tip.*

EXPLAIN THAT this difference in resistance, or friction, is a result of the scales overlapping each other in a single direction along the hair fibre. This scale arrangement causes a ridge, which points away from the fibre base.

NOTE THAT participants may find the difference in resistance hard to feel if they have used a hair straightening iron as the scales are compressed under heat and pressure by the iron.

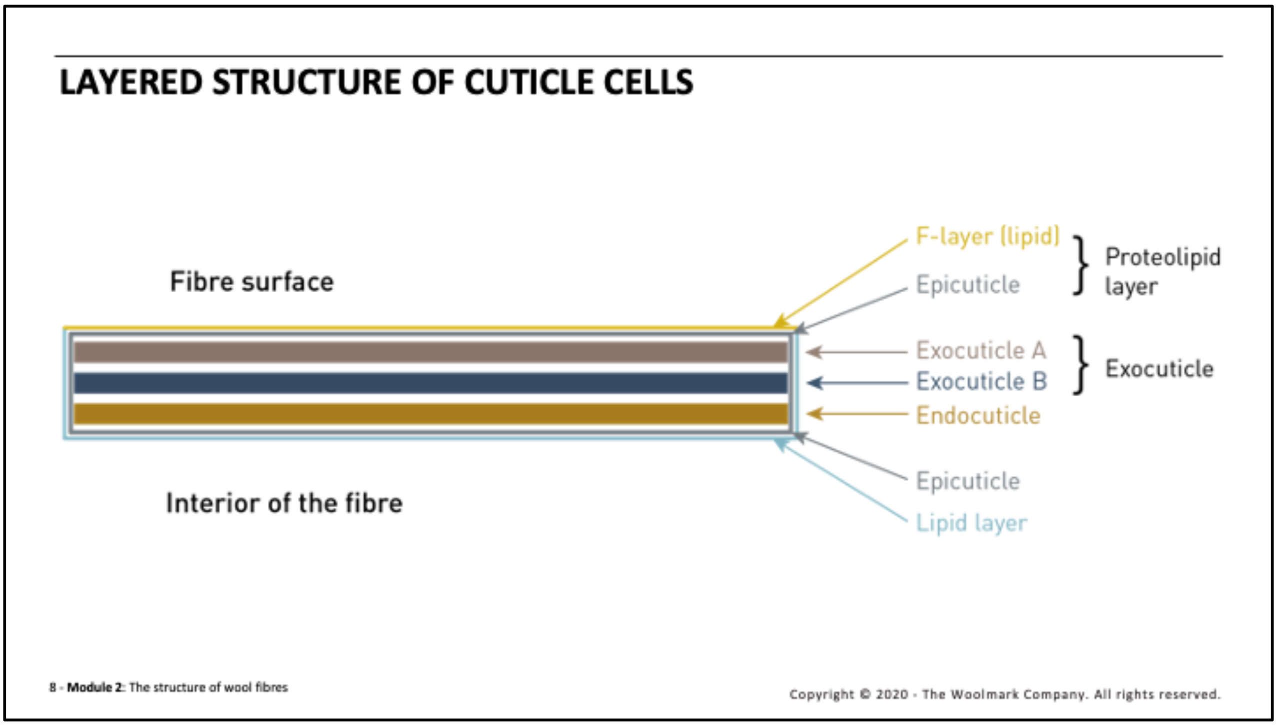
INFORM participants that this difference in resistance is called the 'directional frictional effect' (DFE), which will be discussed shortly.



REFER participants to the images on the slide as you explain that the pattern of the cuticle cells (scales) on the surface of animal fibres varies with animal type (e.g. sheep, alpaca, camel, goat, rabbit etc) and with the diameter of the fibre.

INFORM participants that microscopic examination of a fibre can identify the animal that produced the fibre.

EXPLAIN THAT the height of the scales also can be used to identify fibre types. For example, cashmere goat fibres have a lower scale height than wool fibres of the same diameter, as illustrated in the images on the slide.



REFER TO the diagram on the slide as you explain that each cuticle cell in the wool fibre comprises a layered structure. This layered structure is a critical component of a number of the wool fibre's resulting properties.

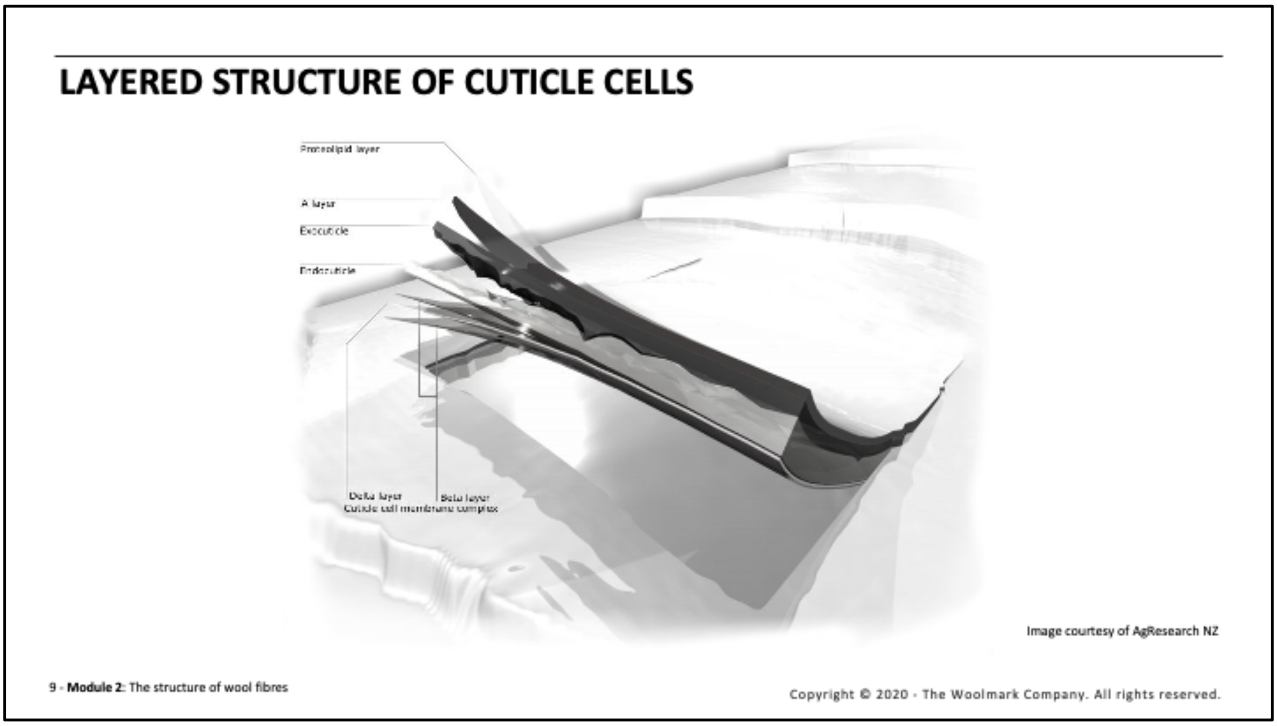
INDICATE THAT each cuticle cell is made up of five layers:

- F-layer
- Epicuticle

NOTE: The F-layer and epicuticle are sometimes viewed as a single layer called the 'proteolipid layer', or the 'resistant membrane'. More recently this combination has also been called the 'fibre cuticle surface membrane' (FCUSM).

- Exocuticle, which is comprised of two layers:
    - Exocuticle A (heavily crosslinked)
    - Exocuticle B (less heavily crosslinked)
- Endocuticle

EXPLAIN THAT the epicuticle encapsulates the cuticle cell, however there may be differences in the lipids on the surface of the cuticle cell (F-layer) compared with the underside of cuticle cell, indicated by the different colour and label (Lipid layer) on the diagram.

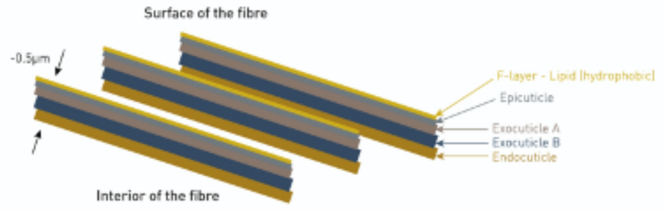


EXPLAIN THAT this slide shows an alternative cross-sectional view of the cuticle cell and its various layers.

In this view:

- the F-layer and epicuticle are shown as a single proteolipid layer.
- the exocuticle A layer is represented as the A layer
- the exocuticle B layer is labelled as the exocuticle
- the endocuticle lies between the exocuticle and the cell membrane complex (CMC), which separates the cuticle cells from the cortical cells. The beta layers of the CMC contain a waxy lipid material, similar to that found on the surface of the wool fibre (the F-layer) and the delta layer, which is believed to be made of non-keratinous protein that sits between cells. The CMC will be discussed in detail later in this module.

LAYERED STRUCTURE OF CUTICLE CELLS (continued)



The surface layers of a wool fibre

The F-layer:

- controls the friction between fibres
- controls the 'wetting' properties of the fibre
- determine the surface free energy (SFE) of the fibre

10 - **Module 2**: The structure of wool fibres

EXPLAIN THAT the hydrophobic (water-resistant) lipid F-layer on the surface of the cuticle cells:

- comprises ~0.03% of the weight of the fibre
- is composed primarily of 18-methyleicosanic acid (an organic acid).

EXPLAIN THAT the F-layer:

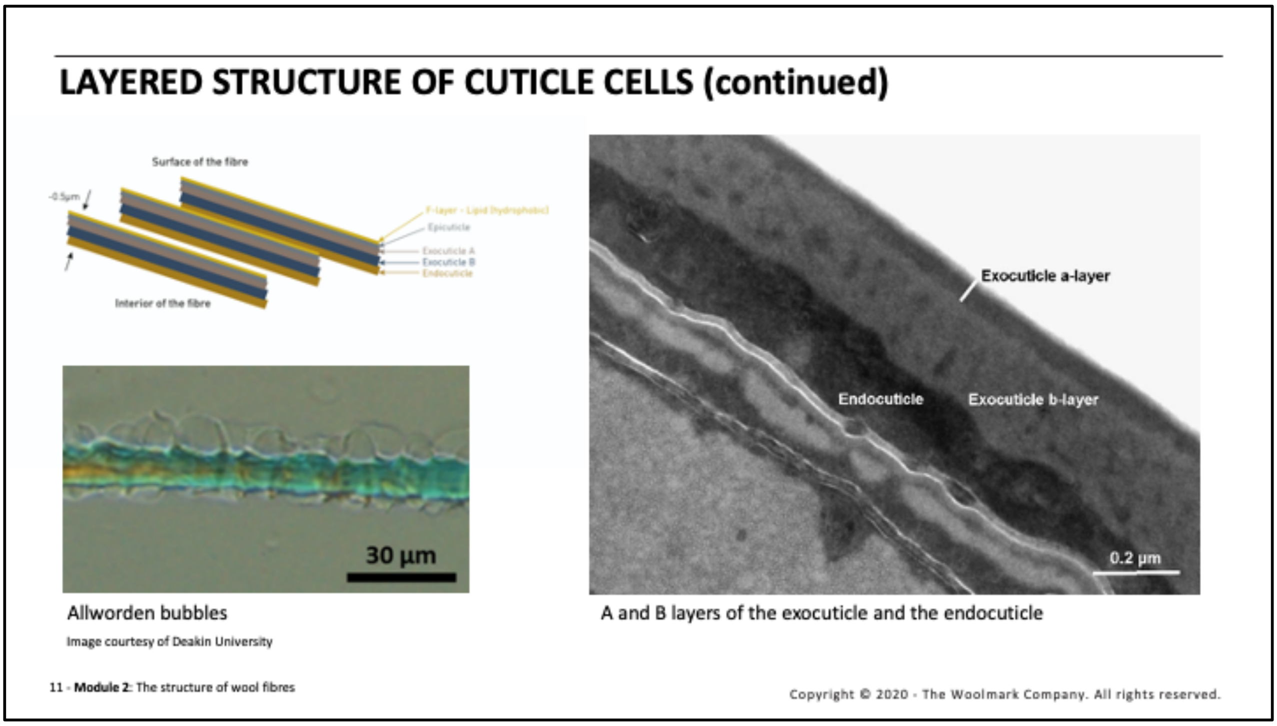
- controls the friction between the wool fibres. The lipid makes the fibre surface friction low. Without the lipid layer the protein is exposed and friction is high.
- controls the 'wetting' properties of the fibre. The lipid layer provides a hydrophobic (water-resistant) layer on the fibre, which reduces the rate of wetting. Without the lipid layer (i.e. delipidised wool), the fibre wets out (spreads across the surface of the fibre more rapidly) much faster
- determines the surface free energy (SFE) of the fibre. Surface free energy is the measure of the ease with which wool fibres may be wet by liquids, such as water and to which some materials adhere.
    - The higher the SFE, the easier the fibre is to wet out.
    - The lower the SFE, the harder it is to wet out.

SUMMARISE by reinforcing that the F-layer is important in determining how the fibre (and subsequent fabric) feels and how easily it wets.

***DEMONSTRATE** the concept of wetting out by dipping an untreated wool sample and a delipidised wool sample in a cylinder of water for several seconds before removing them and ask participants to observe which sample 'wet out' fastest (i.e. the delipidised wool).*

***NOTE:** If practical and appropriate, ask for two participants to carry out the demonstration to encourage hands-on learning and to build rapport with the group. Ask each participant to submerge their sample as the rest of the group observes the results.*

EXPLAIN THAT wool processors generally try to avoid damaging this F-layer, although some chemical finishes are designed to damage this component of the wool fibre (e.g. felt-resist treatment, which will be discussed in more detail in a later module).



EXPLAIN THAT the epicuticle is the 'resistant membrane' surrounding the cuticle cells within the fibre, but is also related to the resistant membrane that surrounds many biological cells.

It is proteinaceous, about 2–7mm thick and resists oxidation by chlorine.

DIRECT participants to the image on the slide labelled 'Allworden bubbles' as you explain that when a wool fibre is placed in chlorine or bromine water, bubbles or sacs develop on the surface (known as an 'Allworden reaction').

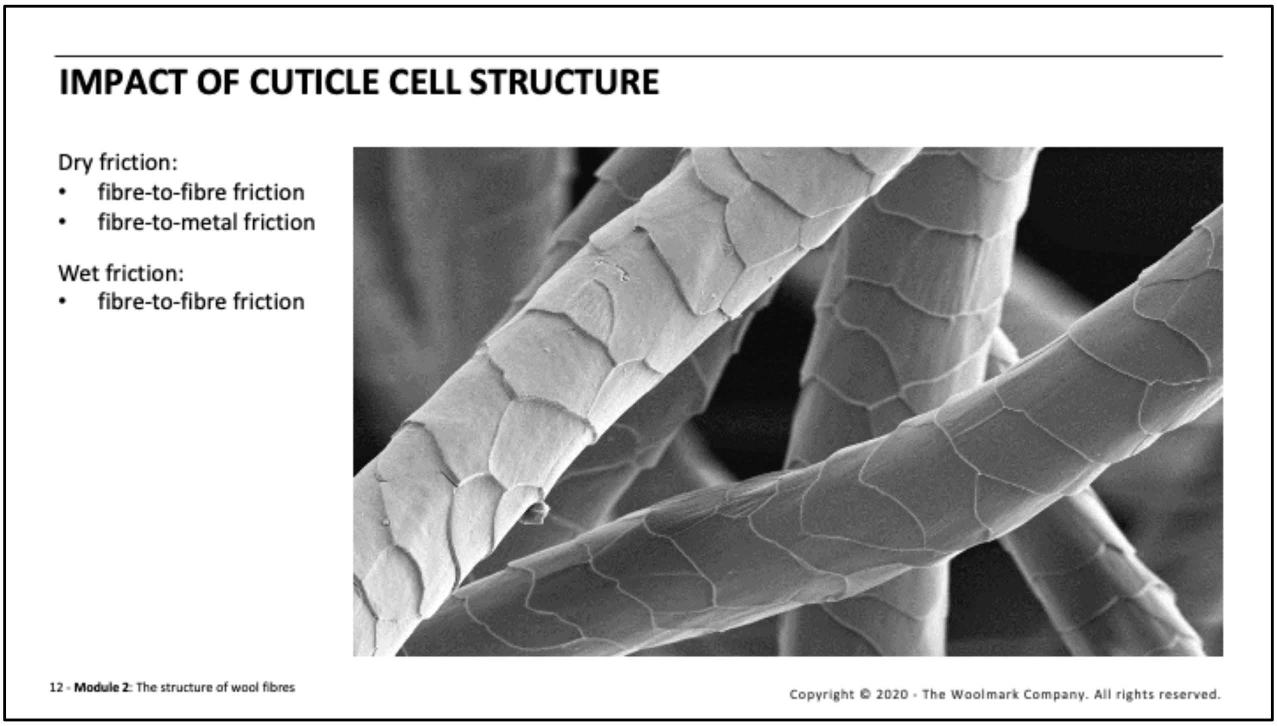
EXPLAIN THAT the raised sacs show the 'epicuticle', or resistant membrane. The sacs are filled with liquid containing solubilised protein from the exocuticle.

EXPLAIN THAT the exocuticle contains two layers (A and B, as shown on the slide) and is a hard highly-crosslinked material, which protects the wool fibre and resists swelling in water. It forms about 60% of the cuticle cell.

The A-layer (~30-50% of the total exocuticle material) is harder than the B-layer. The difference can be seen in the electron microscope image shown on slide.

INFORM participants that the exocuticle softens quickly in chlorine water. The chlorine breaks the stabilising crosslinks, allowing the protein to soften and ultimately dissolve, forming the liquid in the Allworden bubbles.

EXPLAIN THAT the exocuticle (shown as the dark layer in the image on the slide) is mechanically weaker than the other parts of the cuticle, and swells when exposed to water.



INDICATE THAT you will now discuss the impact the cuticle cell structure on the frictional properties the fibre.

DRAW participants' attention to the image on the slide as you explain that the overlapping cuticle cells control the friction between adjacent wool fibres in yarn and fabric (fibre-to-fibre friction), and the friction between the fibres and metal components during processing (fibre-to-metal friction).

EXPLAIN THAT the friction between fibres varies between dry and wet wool, and the degree of damage apparent in the wool fibre itself. Removing or damaging the cuticle cells (especially the F-layer) increases the friction at normal moisture content or regain (i.e. dry friction) as well as wet friction of the fibre.

EXPLAIN THAT dry friction between fibres (either in yarn of fabric form) impacts on fabric properties related to handle.

- If the friction is low (e.g. in undamaged wool) the relative movement of fibres is relatively easy and the fabric deforms (e.g. folds or creases) while retaining a soft 'handle' or 'feel'.
- If the friction is high (e.g. in damaged wool) the relative movement of fibres is more difficult and the deformed fabric feels harsher.

NOTE THAT dry fibre-to fibre friction also affects carding, top-making and spinning processes.

EXPLAIN THAT dry friction between wool fibres and metal affects:

- carding and combing operations
- winding of yarns
- knitting and weaving of yarns.

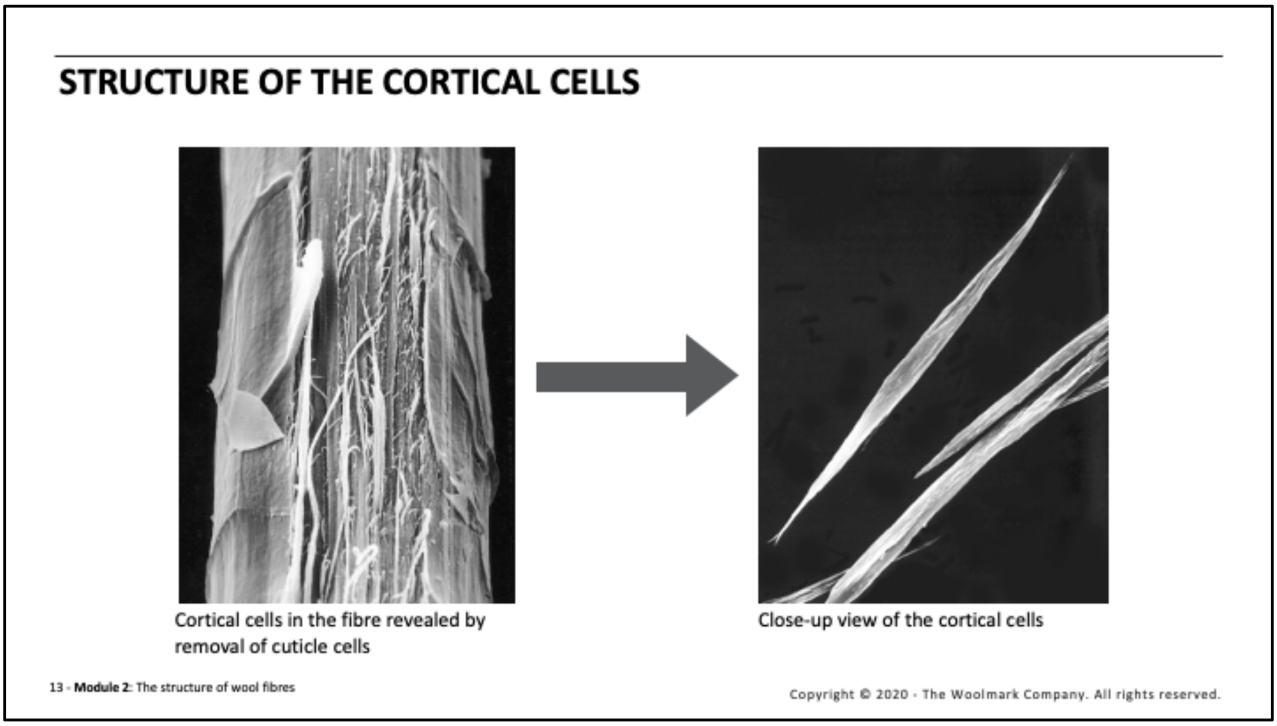
EXPLAIN THAT wet friction between wool fibres affects:

- felting during scouring of raw wool
- felting during milling of fabrics
- felting during aftercare of garments.

NOTE THAT the subject of felting will be covered in detail in *Module 7 The shrinkage of wool products*.

SUMMARISE by reinforcing that the greater the dry fibre-to-fibre and fibre-to-metal friction:

- the stiffer and harsher the fabric handle
- the more fibre breakage during processing
- the more the yarn will tend to break during knitting and winding.



NOTE THAT you will now move from discussing the cuticle cells to explore the underlying cortical cells within the wool fibre.

EXPLAIN THAT cortical cells are:

- are spindle shaped (as shown in the left-hand image on the slide)
- form the bulk of the wool fibre
- are largely responsible for the mechanical properties of the fibre
- are ~100µm long
- are 3-6µm wide
- can be separated by enzymes and ultrasonic disruption.

INDICATE THAT cortical cells contain both crystalline and non-crystalline regions.

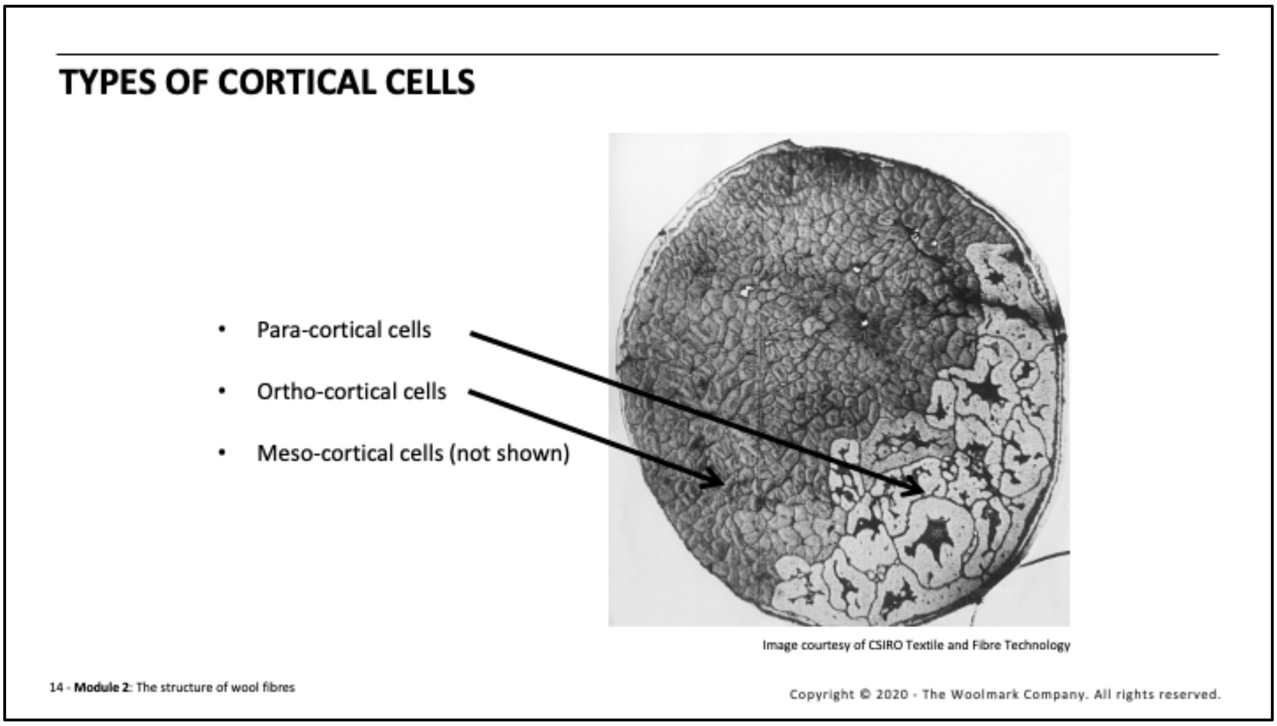
EXPLAIN THAT the crystalline region:

- has a crystal-like structure
- defines the fibre's stiffness, strength and resiliency
- is composed of rodlike components called microfibrils or 'intermediate filaments'.

EXPLAIN THAT the non-crystalline region:

- is high in sulphur
- is where the dyes and absorbed water resides
- controls setting and relaxation properties
- is sometimes called the 'matrix material'.

INFORM participants that the cortical cells also contain up to 13% non-keratinous protein, which contains low sulphur and high glycine tyrosine type materials, and some lipid material.



REFER participants to the image on the slide as you explain there are three types of cortical cells in wool fibres, which differ in:

- crystallinity
- sulphur content
- rate of dye and water uptake.

EXPLAIN THAT the ortho-cortical cells:

- are more crystalline
- contain less sulphur
- take up water (and hence dye) more slowly.
- are more reactive (due to differences in the non-crystalline material)
- swell less than para-cortical cells when adsorbing water.

EXPLAIN THAT the para-cortical cells:

- are less crystalline
- contain more sulphur
- take up water (and hence dye) quickly
- swell more than ortho-cortical cells when adsorbing water.

EXPLAIN THAT the meso-cortical cells, which are not shown on the slide are smaller in number (they make up ~4% of fibre) and have little impact on water (and hence dye) uptake.

EMPHASISE THAT the difference in dye uptake by the cortical cells rarely has any impact on the appearance of dyed wool. The distribution of dye across the fibre depends on the type of dye as well as the dyeing conditions.

ENCOURAGE participants to note the bilateral distribution of the cortical cells shown in the cross-section of the fibre shown on the slide, which is associated with crimp in the fibre.

TYPES OF CORTICAL CELLS

Average number of each type of cortical cell per transverse section of each crimp group, across all samples combined, and total number of cortical cells per fibre cross-section.

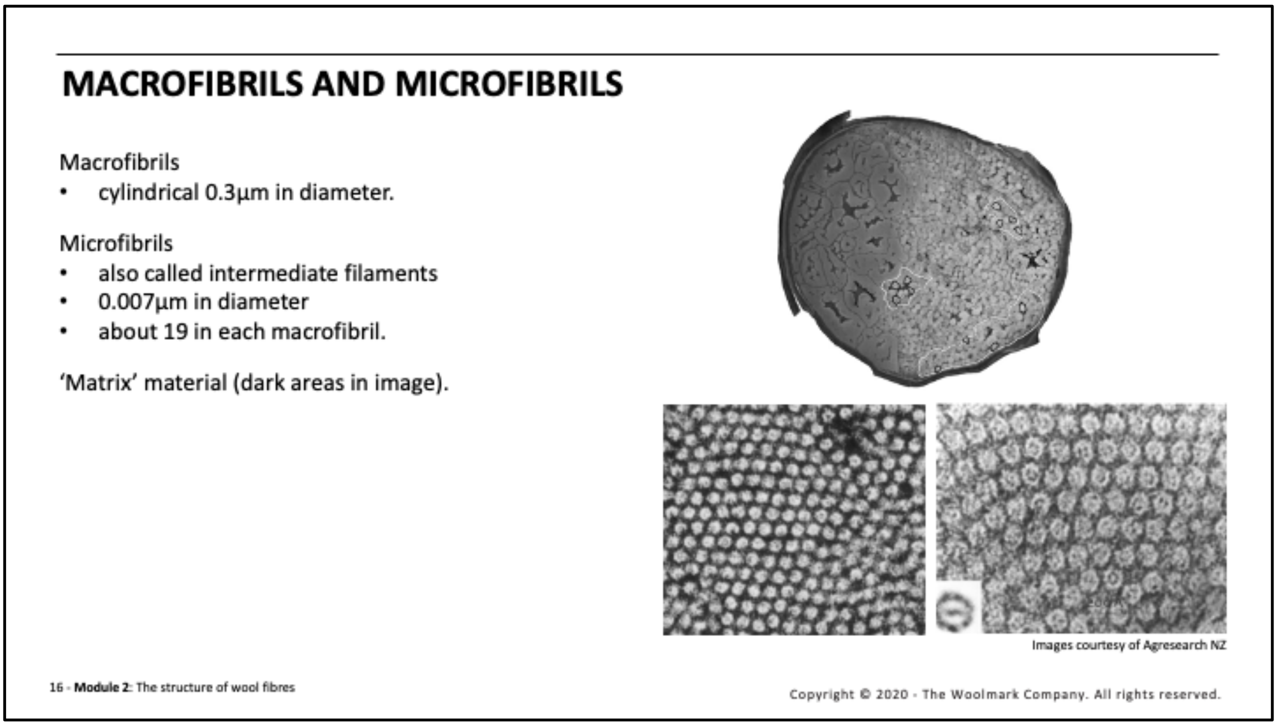
	CRIMP GROUP			
	LOW	MEDIUM	HIGH	MEAN
Cell type	Number of cells			
Ortho-cortical	21.1	21.8	19.6	20.9
Para-cortical	16.0	16.3	18.2	16.8
Meso-cortical	2.4	3.0	2.3	2.6
Total	39.6	41.1	40.1	40.3

Adapted from Agresearch NZ

15 - **Module 2**: The structure of wool fibres

EXPLAIN THAT the table on the slide shows the relative number of each type of cortical cell in a wool fibre. As illustrated in the table, typically there are more ortho-cortical cells, somewhat fewer para-cortical cells and relatively few meso-cortical cells.

POINT OUT while the average number differs slightly with crimp type, the pattern is the same in high, medium and low crimp Merino wools.



EXPLAIN THAT the structure of the cortical cells has been investigated using transmission electron microscopy. This technology allows us to take a closer look inside the wool fibre, as illustrated on the slide.

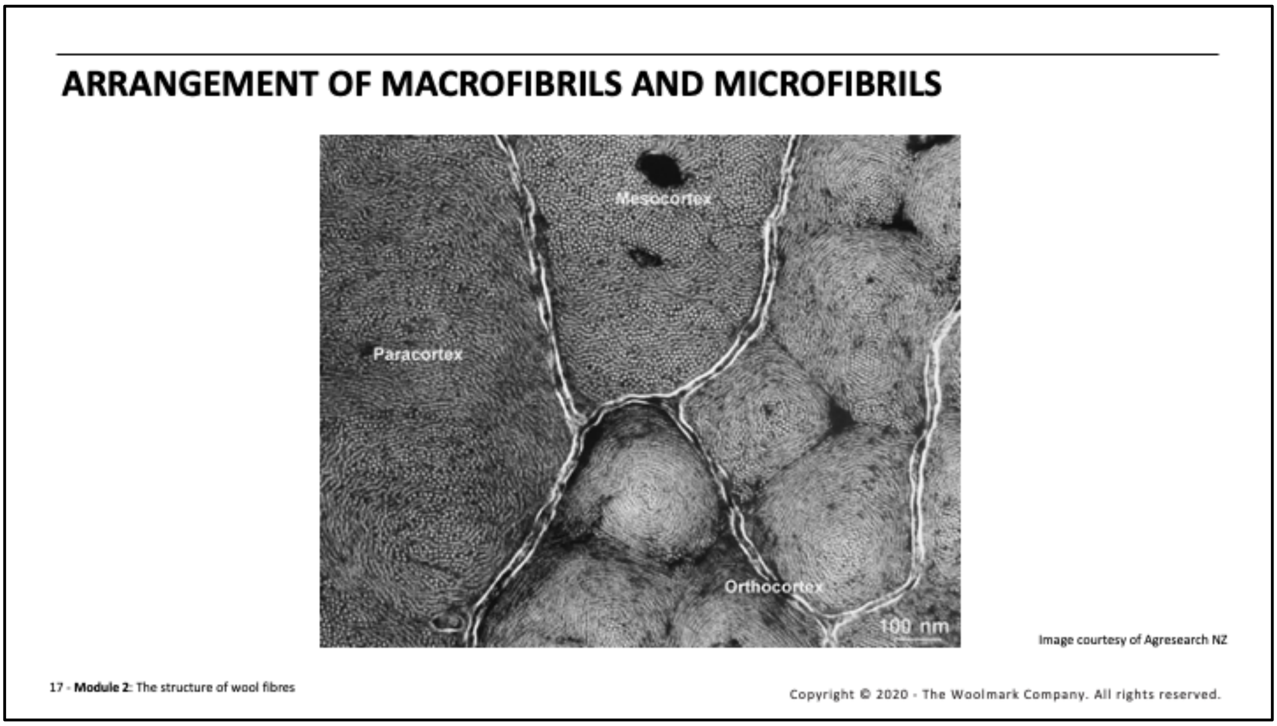
EXPLAIN THAT the cortical cells are made up of:

- macrofibrils, which are cylindrical in shape and about 0.3µm in diameter
- microfibrils (recently called 'intermediate filaments'), which are about 0.007µm in diameter. There are about 19 microfibrils in each macrofibril.
- alpha-helical material composed of proteins that form coils and make up all crystalline materials.

EXPLAIN THAT the electron micrographs on the slide illustrate:

- the macrofibrils
- the intermediate filaments (or microfibrils) — seen as white dots in the more heavily-stained matrix material.

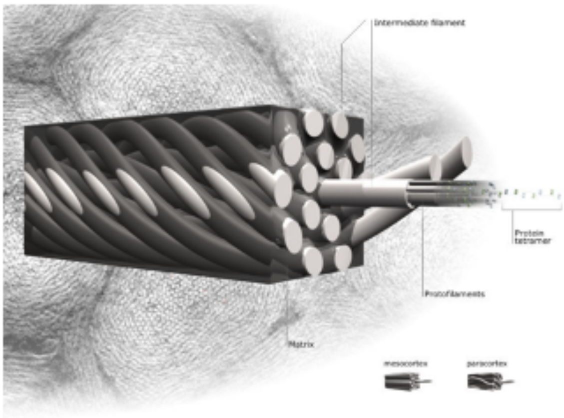
EXPLAIN THAT the dark regions in the images indicate the 'matrix' regions of the cells.



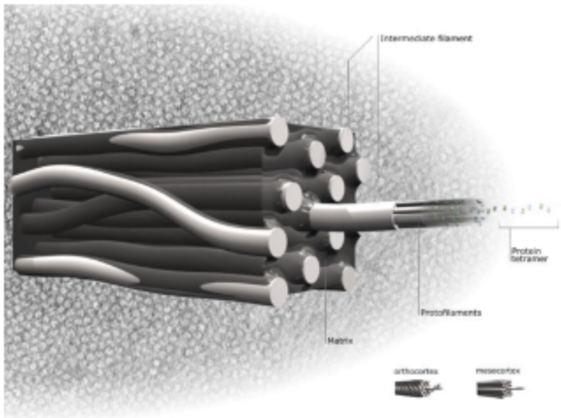
EXPLAIN THAT the transmission electron micrograph of cortical cells shown in the slide reveals differences in the arrangement of macrofibrils and microfibrils in the various types of cortical cells.

INDICATE THAT the filaments within the ortho-cortical cells appear less well aligned with the axis of the fibre than the filaments in the other cell types. This gives the impression the filaments within the ortho-cortical cells are lying at an angle to the cell axis.

TYPES OF CORTICAL CELLS



Ortho-cortical cell



Para-cortical cell

Images courtesy of Agresearch NZ

18 - **Module 2**: The structure of wool fibres

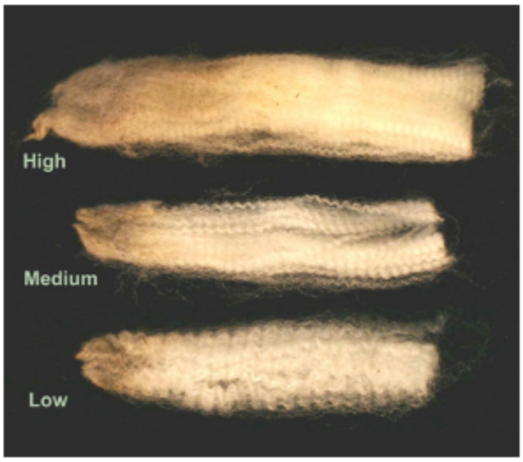
EXPLAIN THAT the above images are reconstructions of the arrangement of the intermediate filament (microfibril) structures within the ortho-cortical and para-cortical cells.

NOTE FROM the illustrations in the slide that the intermediate filaments in the:

- ortho-cortical cells are in a more helical (twisted) conformation, like the fibres in a spun yarn
- para-cortical cells are straighter, like the filaments in a low-twist filament yarn
- meso-cortical cells are even straighter, and are shown as insets on the slide.

FIBRE CRIMP

Cross-section of a wool fibre



Variation in wool fibre crimp

Image courtesy of CSIRO (Australia)

19 - **Module 2**: The structure of wool fibres

HAND OUT staples of greasy wool of varying crimp and allow participants to explore as you cover the next few slides.

EXPLAIN THAT this slide illustrates the 'crimp' in the wool fibre, which appears as 'waves' in the aligned fibres of a wool staple.

ASK participants to note the crimp in the fibre samples as they are circulated among the participants.

EXPLAIN THAT crimp is most commonly observed in fine wool and is associated with the bilateral distribution of ortho-cortical and para-cortical cells in fibres up to ~25µm (as illustrated in the cross-section image on the slide).

NOTE THAT some sheep breeds have a 'core annulus' structure of cortical cells (i.e. a central core with surrounding cells) as opposed to the bilateral distribution shown here.

IMPACT OF CRIMP

20 - **Module 2**: The structure of wool fibres

EXPLAIN THAT the crimp in wool can affect subsequent processing. High crimp wools entangle more easily during processing. This helps reduce pilling in the fabric as the fibres are more locked into each other.

EXPLAIN THAT crimp levels also impact the final product. High-crimp wool:

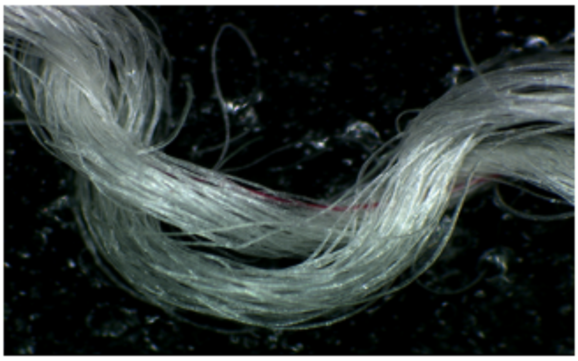
- improves top (and fabric) yield
- produces bulkier yarns (favoured for knitted products) and fabrics
- feels a little rougher (not as smooth) than low crimp wool in woven products.

INDICATE THAT fabric and yarn properties are affected by fibre crimp. Fabrics produced using high-crimp wool are less dimensionally stable than fabrics from low-crimp wool.

***HAND OUT** the samples of fabric made from high-crimp and low-crimp wool and ask participants to observe the way it looks and feels. Allow participants to pass the sample around as you continue the lecture.*

***NOTE:** Remember to collect the samples when all participants have finished as it will be required again later in this module.*

FIBRE CRIMP



Low-crimp wool yarn

High-crimp wool yarn

Image courtesy of CSIRO (Australia)

21 - **Module 2**: The structure of wool fibres

INDICATE to participants that the image on the left of the slide is a micrograph of a pure wool yarn made using low-crimp wool.

INDICATE to participants that the image on the right is a micrograph of a pure wool yarn made of high-crimp wool

ENCOURAGE participants to note**:**

- The alignment of the low-crimp fibre to the twist in the yarn.
- The low-crimp wool yarn is smooth and lean compared with yarns from higher-crimp wools.
- It is relative easy for the fibre to slip out of this yarn compared with higher-crimp wools.
- Pilling will be higher in products made using this yarn.

ENCOURAGE participants to note**:**

- The somewhat random arrangement of the high-crimp fibre to the twist in the yarns.
- The yarn is thicker and somewhat bulkier compared with yarns from lower-crimp wools.
- It is much more difficult for the fibres to slip out of this yarn compared with lower-crimp wools.
- Pilling will be less in products made using this yarn.

IMPACTS OF CORTICAL CELL STRUCTURE

- Cortical cells control:
  - fibre crimp
  - moisture uptake
  - dye uptake
  - tensile and bending properties of the fibres
  - stress relaxation properties of the fibres.
- Damage to the cortical cells can result in:
  - reduced fabric bulk
  - reduced product comfort
  - reduced fabric strength
  - impaired wrinkle recovery.

22 - **Module 2**: The structure of wool fibres

SUMMARISE the impact of cortical cell structure on the fibre properties and the potential impacts of damage to this structure on wool fabric.

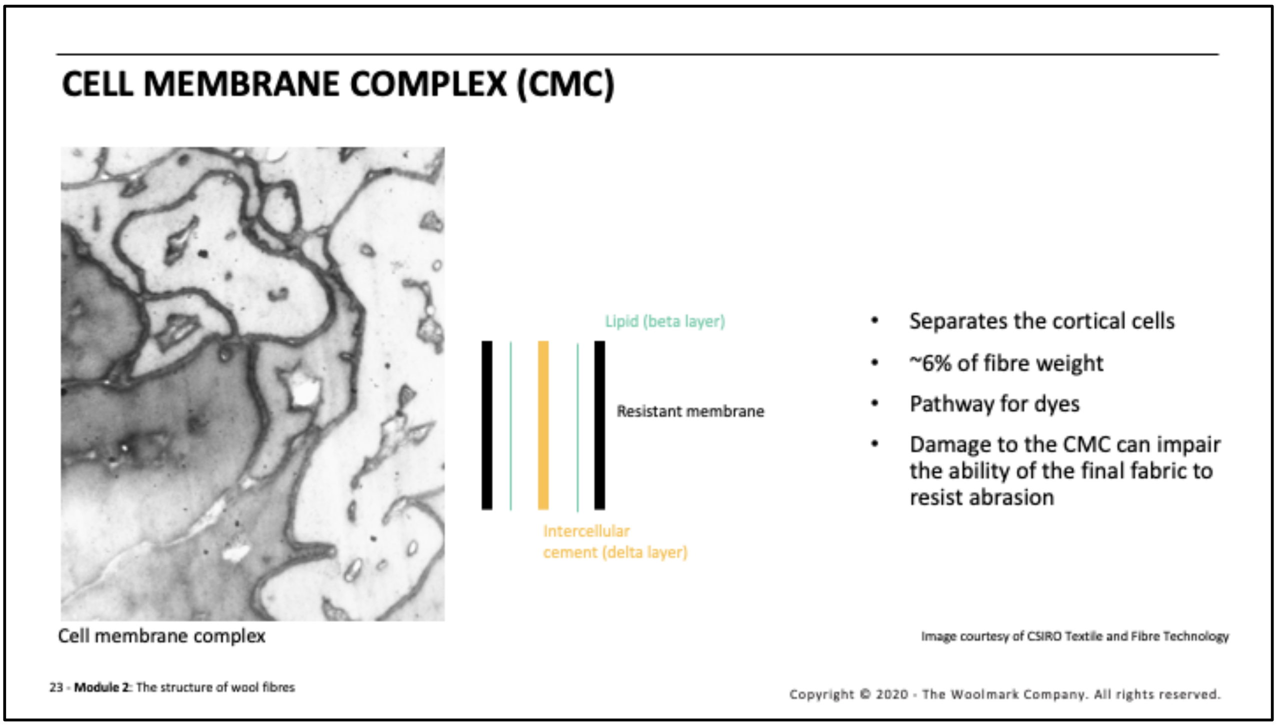
REINFORCE THAT cortical cells control:

- fibre crimp, due to the bilateral distribution of the cells in fibres up to ~25µm
- moisture uptake
- dye uptake
- tensile and bending properties of the fibres
- stress relaxation properties of the fibres.

EMPHASISE THAT the finishing process aims to avoid damage to the cortical cells or, where damage is inevitable, damage must be even.

EXPLAIN THAT damage to the cortical cells can result in:

- reduced fabric bulk
- reduced product comfort
- reduced fabric strength
- impaired wrinkle recovery.



EXPLAIN THAT you will now move onto the cell membrane complex (CMC), which separates the cortical and cuticle cells.

INDICATE THAT the CMC contains a waxy lipid material, similar to that found on the surface of the wool fibre (F-layer) and comprises about 6% of the total fibre weight.

REFER TO the image on the slide as you point out that transmission electron microscopy of stained fibres reveals the CMC has a fine structure.

REFER TO the diagram beside the image on the slide as you explain that CMC comprises:

- the resistant cell membrane, which surrounds all cortical cells
- a lightly-stained layer (called the beta layer), which is thought to be the lipid that adheres to the membrane
- a layer (called the delta layer), which is believed to be made of non-keratinous protein that sits between cells. This layer is:
    - thought to provide adhesion between the cells and is also called the 'intercellular cement'
    - of variable thickness
    - dissolves in formic acid or with enzymes.

EXPLAIN THAT the CMC provides the pathway for dyes in the early stages of the multi-stage dyeing process. It also provides a fracture plane for the fibres under torsion. The CMC is a weak link in the fibre structure. During abrasion fibres can fail by fracturing along the line of the CMC.

INDICATE THAT chemical damage to the CMC can occur during finishing and can impair the ability of the final fabric to resist abrasion. 'Abrasion resistance' is the term used to describe the ability of a fabric to resist damage during wear.

NOTE: 1–2% of the wool fibre is made up of waxy lipid material, which is mainly concentrated in the intercellular regions of the fibre (CMC) and on the surface of the wool fibre (F-layer). This material plays an important role in the dyeing of wool.

IMPACT OF CELL MEMBRANE COMPLEX

- CMC acts as a pathway for dyes.
- Mechanical finishing does not affect the CMC.
- Chemical finishing can affect the CMC.

24 - **Module 2**: The structure of wool fibres

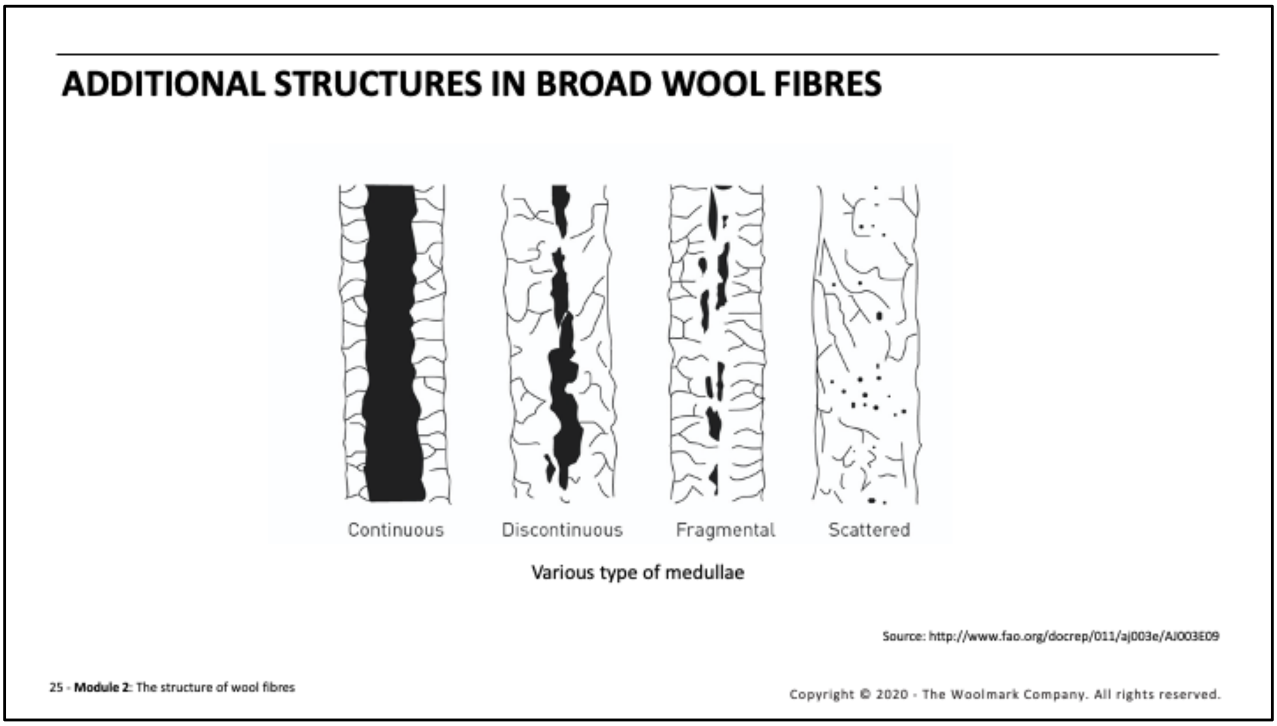
SUMMARISE by explaining the cell membrane complex (CMC) affects fibre properties and processing performance in dyeing operations:

- The CMC acts as the primary pathway for the entry of dyes into the interior of the fibre.
- In these situations damage to the CMC can result in uneven dyeing.

EXPLAIN THAT mechanical processing operations don’t normally affect the CMC directly.

EXPLAIN THAT chemical finishing operations can result in modification to the CMC, which may impair the ability of the fibre to resist abrasion.

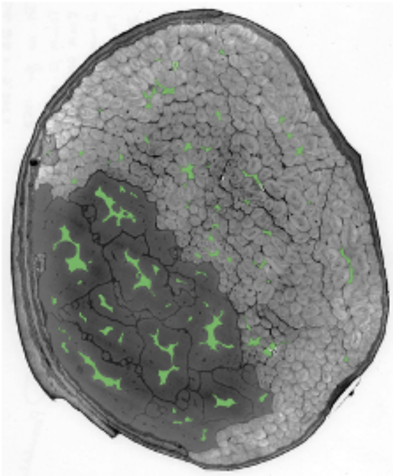
POINT OUT that polar solvents (methanol-butanol and formic acid) can improve abrasion resistance. The mechanism may involve the removal of unbound lipids, which weaken the interface between cells.



MENTION THAT many broad wool fibres have additional structures within the fibre, such as:

- a medulla:
    - a central core of cells containing air-filled space (as depicted in the image on the slide)
    - found in broad wool fibres (>36um)
    - evolved to improve insulation value of the fleece.
- nuclear remnants:
    - These components are present in keratin structures and are derived from the cortical cells in the growing fibre.
    - They form only a minor part of the fibre.
    - Do not appear to have any effect in the fibre properties.

OTHER STRUCTURES — CYTOPLASMIC REMNANTS



Cytoplasmic remnants make up:

- 4.0% of the cortex
- 5.9% of para-cortical and meso-cortical cells
- 2.4% of ortho-cortical cells.

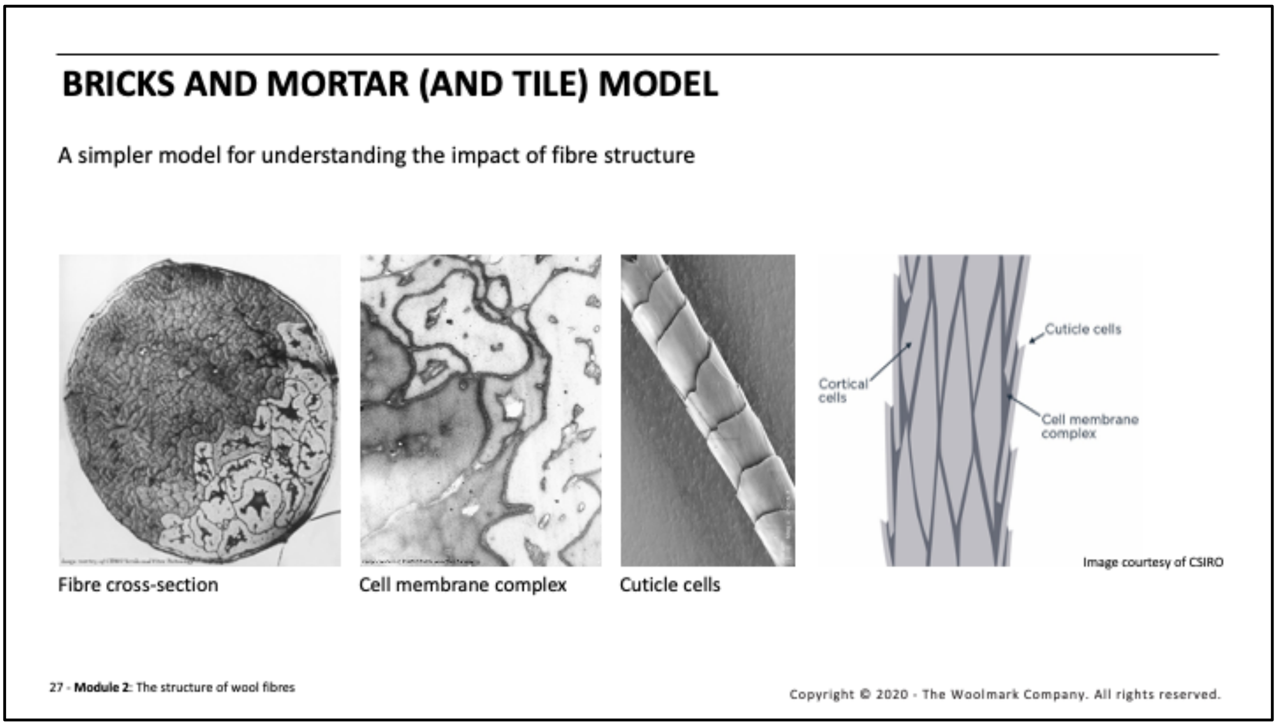
Image courtesy of Agresearch NZ

26 - **Module 2**: The structure of wool fibres

EXPLAIN THAT cytoplasmic remnants (shown in green on the transmission electron microscope image on the slide) are also found in the cortical cells of wool.

NOTE THAT measurements show these remnants constitute about 4% of the cross-sectional area of the wool fibre.

INDICATE THAT more of this material is found in the para-cortical and meso-cortical cells than in the ortho-cortical cells, and there is little difference between high-crimp and low-crimp wools.



REINFORCE THAT the structure of wool is complex. To understand the impact fibre structure has on processing, a much simpler model can be used and is illustrated on the slide.

EXPLAIN THAT this simple structure of wool was developed and used by CSIRO in the 1980s and is called the 'bricks and mortar' model (sometimes the bricks, mortar and tile model).

For the purpose of processing, explain that this model contains all the required information.

REFER TO the diagram on the slide (which appears as a longitudinal cross-section of a fibre) as you explain it has three components:

- spindle-shaped cortical cells (bricks)
- cell membrane complex, which glues together the cortical cells (mortar)
- cuticle cells or scales (tiles).

SUMMARY — MODULE 2

Wool fibres have a complex structure with three major components that impact processing

1. Cuticle cells:
   - Layered structure
   - F-Layer is the most important.
   - Damage to the F-Layer affects both handle and shrinkage.
2. Cortical cells:
   - Three types (ortho-cortical, para-cortical and meso-cortical cells)
   - Damage during finishing can result in:
     – reduced fabric bulk
     – reduced product comfort
     – reduced fabric strength
     – impaired wrinkle recovery.
3. Cell membrane complex (CMC):
   - The pathway for dyes.
   - When damaged, can impair the fabric's ability to resist abrasion.

28 - **Module 2**: The structure of wool fibres

SUMMARISE THIS module by reinforcing that the wool fibre has a highly complex structure, which delivers a range of properties.

REINFORCE that three major components of the wool fibre impact on processing:

- cuticle cells (scales)
- cortical cells
- cell membrane complex.

Cuticle cells

REMIND participants that cuticle cells have a layered structure of which the outer lipid layer (F-layer) is most important in determining the frictional properties of the fibres.

Damage to the F-layer increases both dry and wet friction, in turn affecting both handle (giving a harsher feel) and felting (slowing the process).

Cortical cells

BRIEFLY review the three types of cortical cells (ortho-cortical, para-cortical and meso-cortical), which differ in their ability to take up dye.

REMIND participants that the bilateral distribution of the cortical cells within the fibre is associated with crimp.

REVIEW the finer structures that exist within the cortical cells — macrofibrils and intermediate filaments (microfibrils).

REMIND participants that damage to the cortical cells during processing can result in:

- reduced fabric bulk
- reduced product comfort
- reduced fabric strength
- impaired wrinkle recovery.

BRIEFLY review the cell membrane complex (CMC), reminding participants that the CMC forms the space between the cortical cells and between cortical and cuticle cells.

REINFORCE that it is the pathway for dyes in the early stages of the dyeing process.

REMIND participants that the damage to the CMC during processing will impact on the ability of the fabric to resist abrasion. Some polar solvents increase abrasion resistance of wool by modifying the CMC.

ASK *participants if they have any questions about the content covered in this module.*

ALLOW *time for questions and discussion before proceeding to the final slide and closing the lecture.*

INFORM participants of the time and location for the next lecture — *Module 3 The physics of the wool fibre* — and ensure they read through the relevant notes in their Participant Guides before attending the lecture.

ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in today's lecture.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

BEFORE participants leave ensure you have collected all fibre samples distributed during the lecture.

MODULE 3

THE PHYSICS OF THE WOOL FIBRE

RESOURCES — MODULE 3: THE PHYSICS OF THE WOOL FIBRE

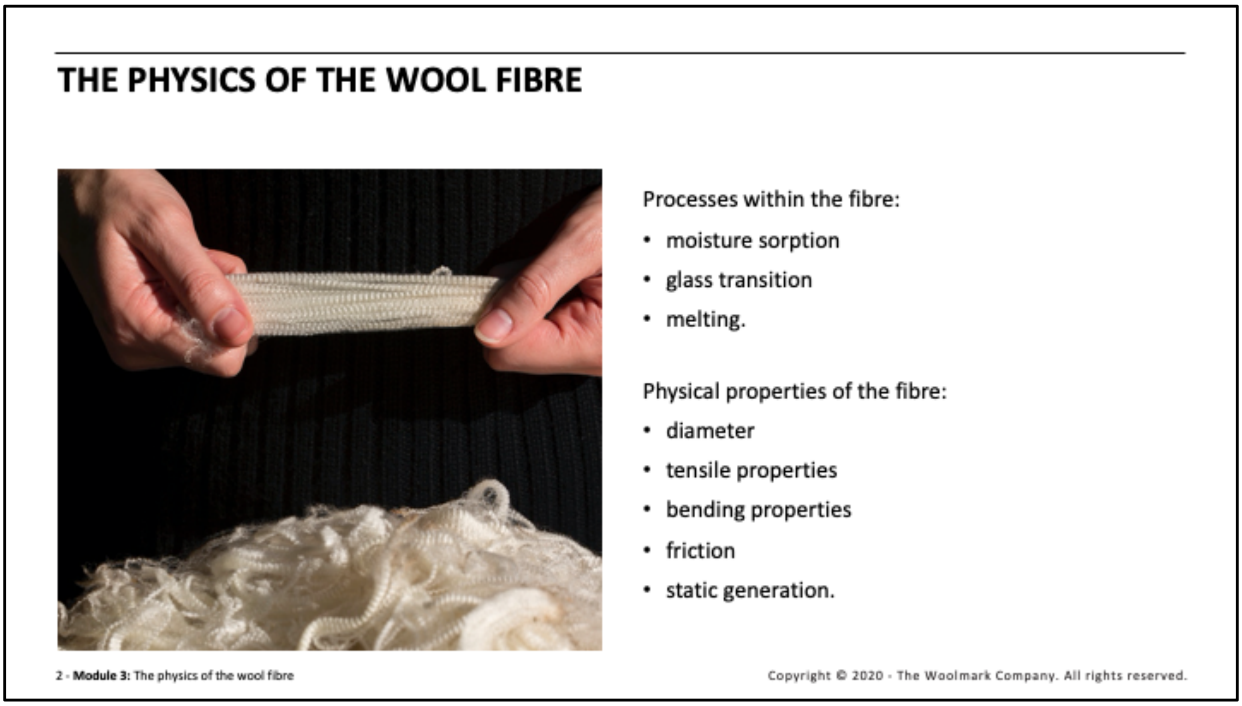
Contained in the *Wool fibre science* Demonstration kit you will find the following resources for use as you deliver **Module 3: The physics of the wool fibre**:

- coarse 'prickly' fabric
- fine 'soft' fabric.

Additional resources to be sourced by the facilitator include:

- rubber hose
- rubber ball
- liquid nitrogen
- polyester or nylon
- gas burner
- tongs
- metal tray
- thick and thin knitting needles
- wet noodles (e.g. udon)
- dry noodles (e.g. rice paper or spaghetti)
- plasticine
- pencil
- balloon (blown up)
- personal protective equipment.

WELCOME participants to Module 3 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The physics of the wool fibre*.



EXPLAIN THAT as outlined on the slide, this module will explore the physical processes within the wool fibre, including:

- the moisture sorption properties of wool fibres
- 'glass transition' and
- 'melting'.

INDICATE THE key physical properties of wool fibres that impact on processing and products will also be covered, including:

- fibre diameter
- tensile properties
- bending properties
- friction (including fibre-to-fibre friction, fibre-to-metal friction and the directional frictional effect)
- static generation.

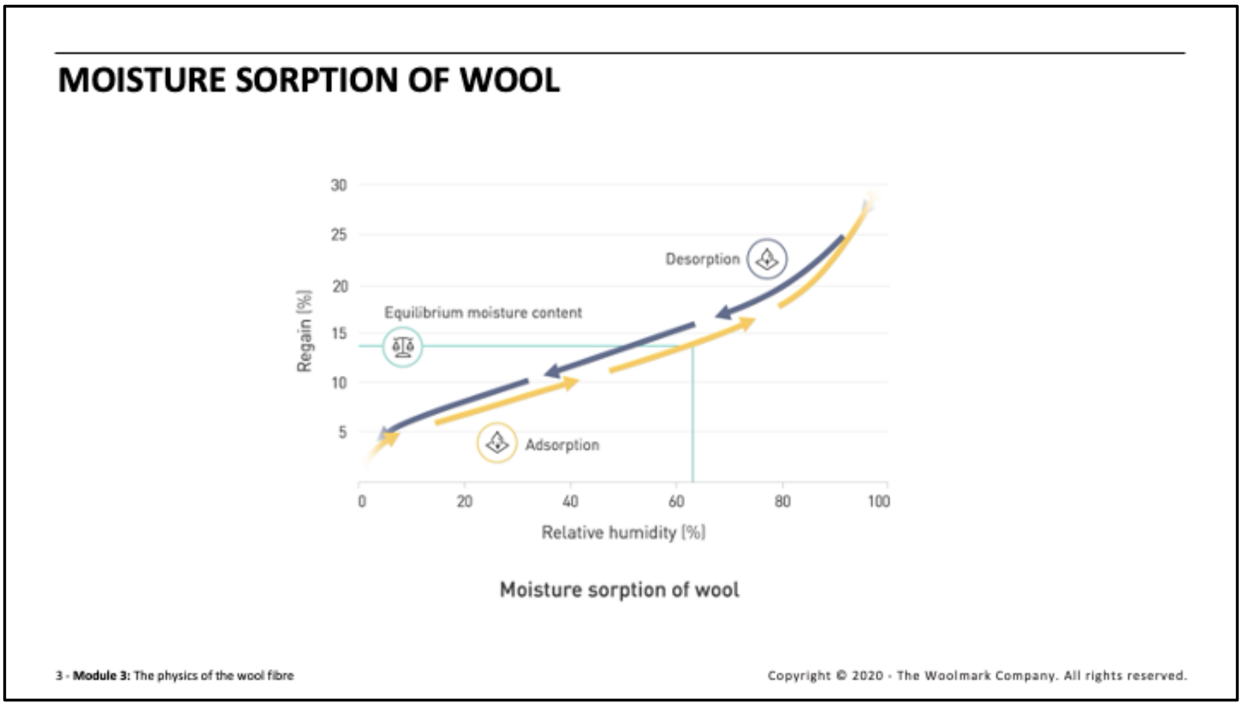
As part of the exploration of wool's tensile and bending properties this module also investigates the concepts of stress relaxation, stress recovery, creep and ageing.

INFORM participants that by the end of this module they will be able to:

- list the five key physical properties of wool fibre (namely diameter, tensile and bending properties, friction and static generation)
- describe the attributes of these physical properties
- explain the impact the glass transition temperature has on the physical properties of the wool fibre and the variables that affect it.
- explain the concept of ageing and the impact ageing has on the physical properties of the wool fibre and the variables that affect it.
- explain the implications of the wool fibre's physical properties on fibre performance.

RESOURCES REQUIRED FOR THIS MODULE

- *coarse 'prickly' fabric*
- *fine 'soft' fabric.*
- *rubber hose*
- *rubber ball*
- *liquid nitrogen*
- *polyester or nylon*
- *gas burner*
- *tongs*
- *metal tray*
- *thick and thin knitting needles*
- *wet noodles (e.g. udon)*
- *dry noodles (e.g. rice paper or spaghetti)*
- *plasticine*
- *pencil*
- *balloon (blown up)*
- *personal protective equipment.*



NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding. Allow the animation on the slide to play before you explain the concept of moisture sorption and desorption in the wool fibre.*

EXPLAIN THAT wool is a hygroscopic material – when wool is completely dry (0% regain as shown on the slide) it will adsorb water from the air until it comes to an equilibrium with the surrounding air.

POINT OUT that wool can adsorb up to 30% of its own weight in water as water vapour.

EXPLAIN THAT the term 'regain' is a measure of the water or moisture content of wool fibre.

REFER TO the graph on the slide as you ask participants to note that wool with a regain of 14% has adsorbed 14% of its own weight in water vapour from the surrounding air. This occurs when the relative humidity (RH) in the air is about 65%.

EXPLAIN THAT the lower curve on the graph shows the change in the equilibrium moisture content of wool as the relative humidity of surrounding air increases (dry = 0% regain, wet ~ 30% regain).

INFORM participants that as wool fibres adsorb water they swell:

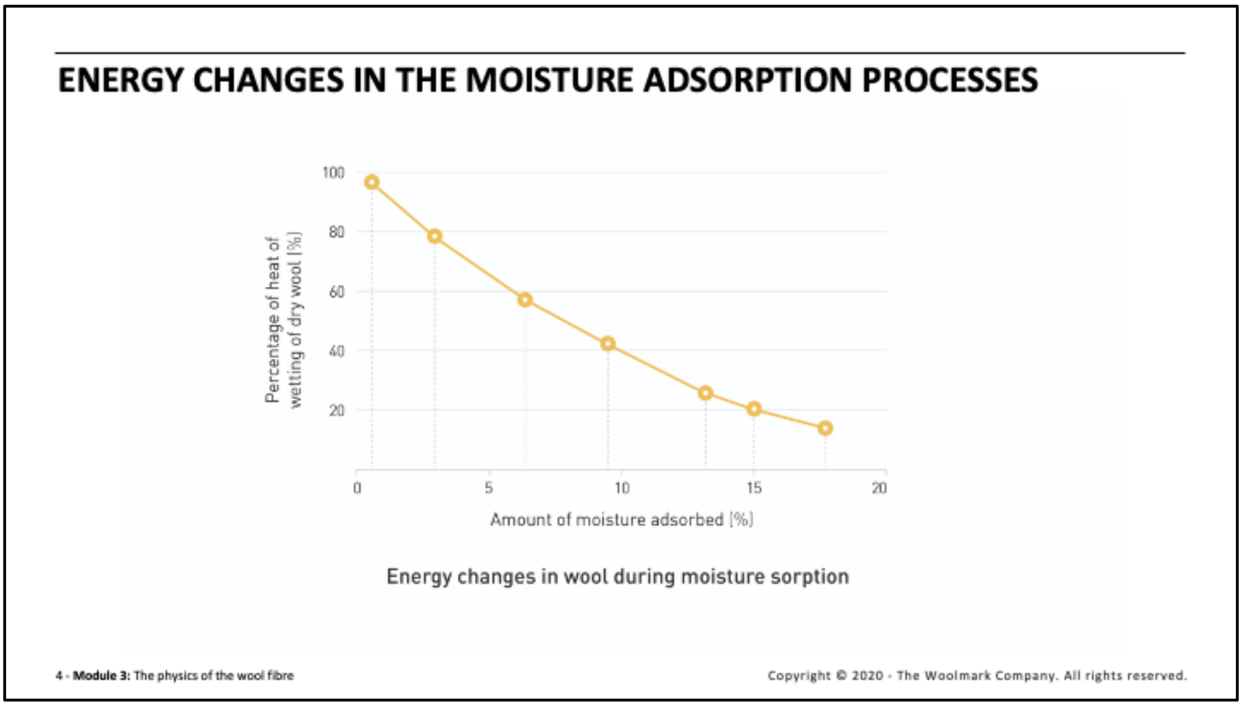
- ~16% in diameter
- ~1% in length.

INDICATE THAT air temperature also affects the equilibrium moisture content to a small extent.

EXPLAIN THAT this process of 'equilibration' with the surrounding air is called 'conditioning'. The rate of conditioning depends on the circulation of the air and can take up to 24hrs even if the wool is well opened.

Under given conditions of temperature and relative humidity of the surrounding air, the equilibrium moisture content of the fibre will be higher when it is drying out (i.e. desorption — shown by the upper curve) than when it is conditioning from dry (i.e. adsorption — shown by the lower curve). This effect is called 'hysteresis' and is seen in many physical processes in the natural world.

NOTE: The adsorbed moisture content (regain) is different from the concept of the 'wettability' of wool. The 'poor wettability' of wool refers to the ability of wool fibres to resist 'wetting' or 'coating' of the fibre by liquid water. Even though undamaged wool resists wetting by liquid water, it will still 'adsorb' and 'desorb' water as water vapour.

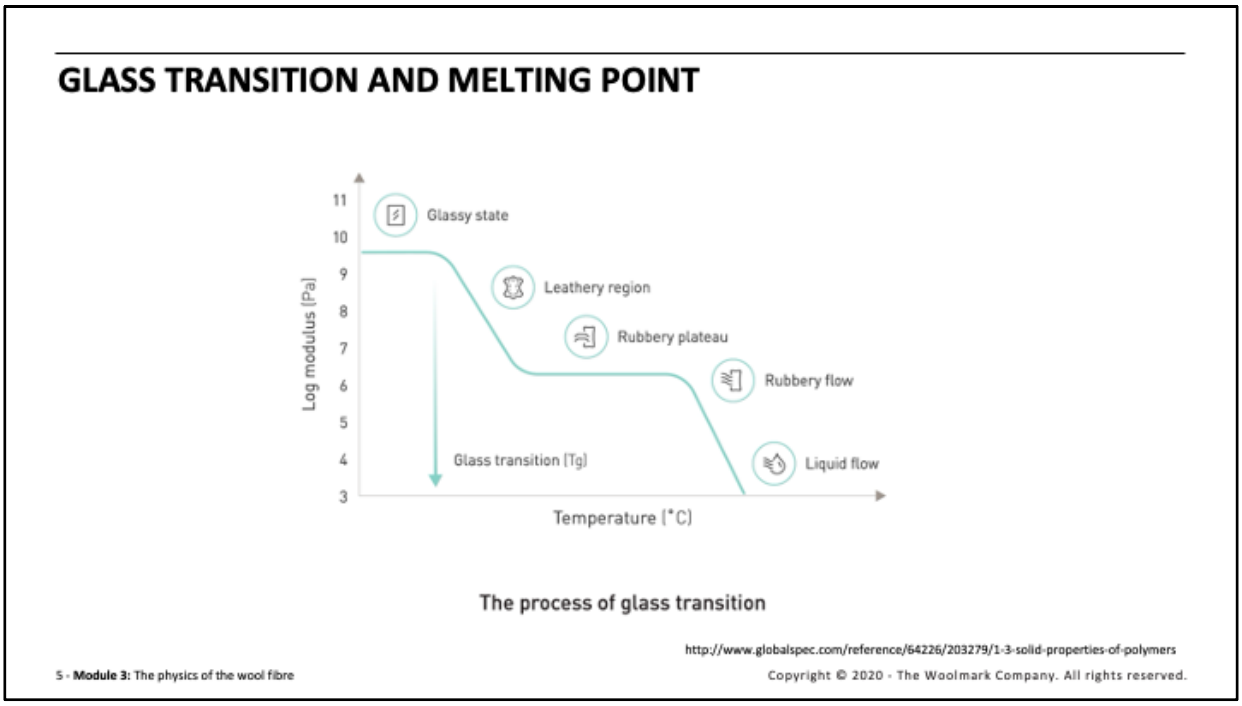


EXPLAIN THAT water adsorption is an exothermic process — energy is released as wool adsorbs moisture, increasing the temperature of the fibre.

REFER TO the graph on the slide as you explain that energy is adsorbed when wool releases moisture to a dry atmosphere, reducing the temperature of the fibre.

NOTE THAT very dry wool releases more energy as it adsorbs moisture than wool at 'normal regain' — 270Wh/kg from dry to wet.

OFFER THE following example to illustrate the impact of this property — when a person walks from a dry area (heated building) into the cold and damp their wool suit releases around 64 kilojoules of energy as it adsorbs moisture from the surrounding air.



***NOTE TO FACILITATOR:** The graph on this slide is animated to enhance participant understanding. The facilitator notes below will guide you as to the recommended time to run the animation.*

EXPLAIN THAT glass transition is a change in the fibre properties of a polymeric material, such as wool, from a stiffer, 'glassy' material to a softer 'rubbery or fluid' material. All semi-crystalline materials (like wool) undergo glass transition as the temperature of the material rises.

The glass transition is a second order phase transition associated with non-crystalline regions of polymers. The transition occurs over a temperature range, which can be broad in non-homogeneous materials (like wool). The temperature of the glass transition depends on the rate of the temperature rise.

PLAY THE ANIMATION as you explain that it shows the change in 'stiffness' (modulus) of a polymeric material with a change in temperature.

EXPLAIN THAT the glass transition temperature (Tg) of the polymer is associated with a significant change in stiffness.

EXPLAIN THAT the melting point refers to the temperature at which crystalline matter changes completely from a solid to a fluid or rubbery material. In crystalline or semi-crystalline polymers (e.g. wool) the melting point of the polymer is also associated with a significant change in stiffness (modulus). Only crystalline or semi-crystalline materials have melting points — the crystal structure is the part of the material that melts.

The melting transition is a first order phase transition associated with crystalline regions of polymers. The transition occurs over a temperature range depending on the size of the crystallites in the crystalline regions.

REINFORCE the following concepts before carrying out the practical demonstration described below:

- Glass transition is a change in the non-crystalline regions of a polymer.
- Melting is a change in the crystalline regions of a polymer.

DEMONSTRATION OF GLASS TRANSITION

Resources required:

- *rubber hose and rubber ball*
- *liquid nitrogen*
- *tongs and gloves for handling cold materials*
- *safety glasses.*

***ASK** a willing participant to bend the rubber hose and bounce the ball — the group can observe the outcomes of each activity.*

***RETRIEVE** the items from the participants and place them in the container of liquid nitrogen for a couple of minutes.*

***REPEAT** the above activities and ask the group to describe the outcome.*

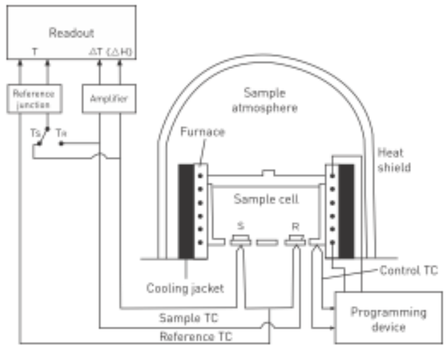
***SUMMARISE** by explaining that by reducing the items below their glass transition temperature they took on the properties of a glass-like state — the hose shattered and the ball did not bounce.*

***NOTE THAT** the items regained their original properties as returned to room temperature.*

MEASURING THE GLASS TRANSITION

Glass transition temperature (Tg) can be determined by measuring :

- the change in properties with temperature, such as:
    - tensile properties
    - bending properties
- differential scanning calorimetry
- differential thermal analysis (DTA)
- atomic force microscopy



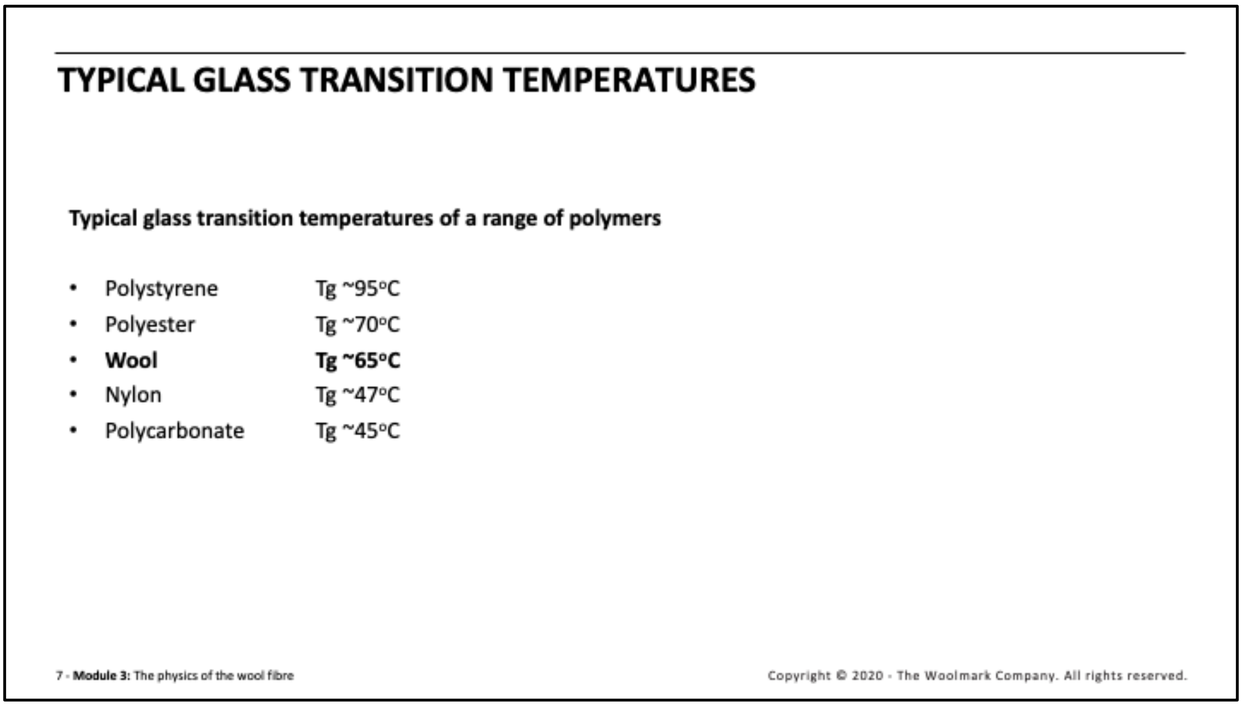
Differential thermal analysis (DTA) instrument

http://www.slideshare.net/VijayMarakatti/thermal-analysistgdta

6 - **Module 3:** The physics of the wool fibre

EXPLAIN THAT the glass transition temperature of polymers can be measured in a variety of ways, including:

- by plotting the change in tensile or bending properties with temperature
    - by measuring the change in the rate of creep under load with temperature
    - by measuring the change in the energy loss in cyclic deformation with temperature
- by using differential scanning calorimetry, which measures the thermal capacity of the polymer
- by using differential thermal analysis (shown on the slide), which measures the temperature difference between the polymer and a standard
- by using atomic force microscopy, which can measure the depth of penetration of a probe into the fibre (the depth of penetration increases rapidly at the glass transition temperature of the material).

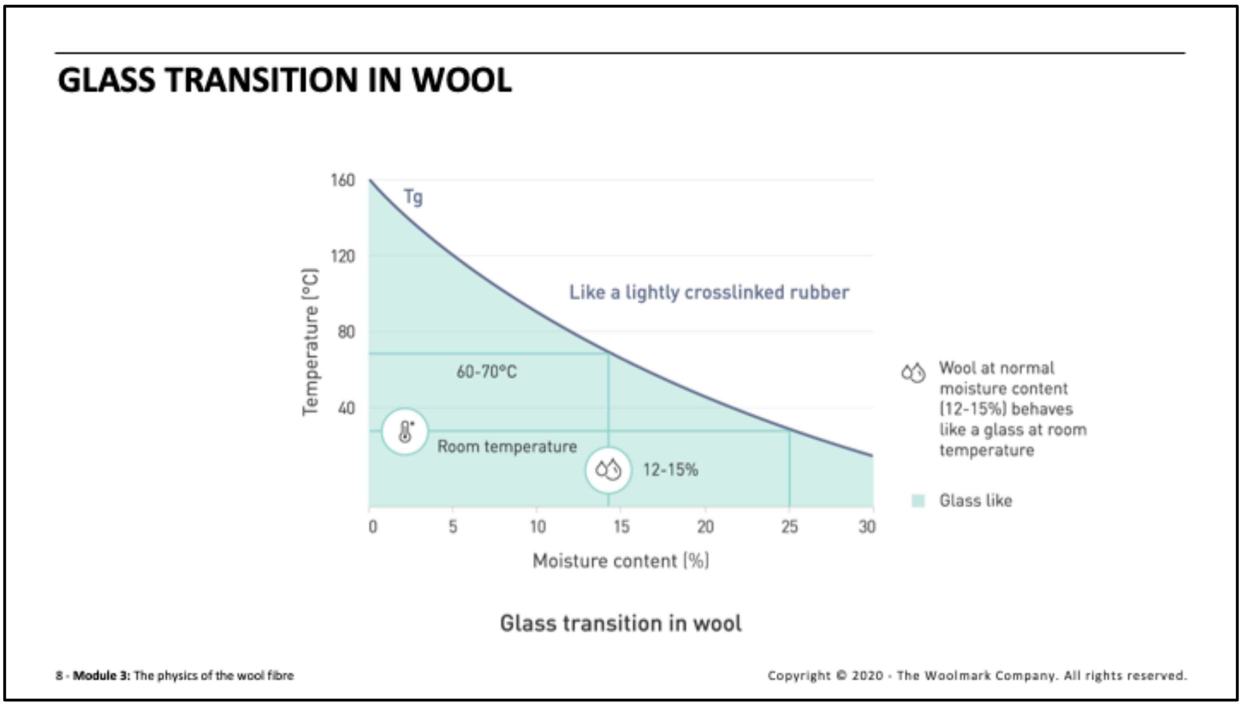


INDICATE THAT typical glass transition temperatures (Tg) for a range of polymers are listed in the table below and on the slide.

• Polystyrene	Tg ~95ºC
• Polyester	Tg ~70ºC
• **Wool**	**Tg~65ºC**
• Nylon	Tg ~47ºC
• Polycarbonate	Tg ~45ºC

POINT OUT that an everyday example of glass transition occurs when heating food in plastic containers in a microwave oven — above its glass transition temperature the container becomes softer and can deform.

EXPLAIN THAT the glass transition of polymers is reduced by the presence of a plasticiser — a compound which is adsorbed by and softens the polymer. For example water plasticises wool and this concept will be explored further later during this module.



NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding.*

PLAY THE *animation as you ask participants to explain what happens to the glass transition temperature of wool as its moisture content increases.*

ACKNOWLEDGE RESPONSES

REINFORCE THAT *the glass transition temperature (Tg) of wool depends on the moisture content of the fibre. Water plasticises the fibre and reduces the Tg.*

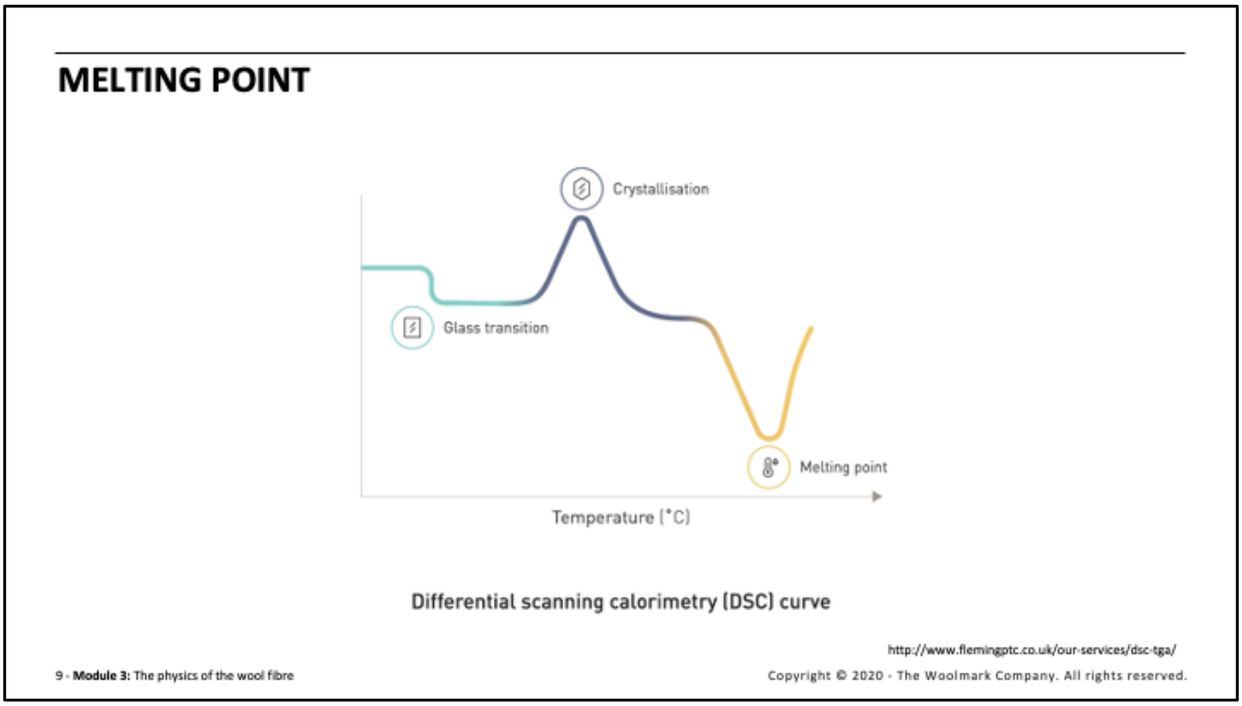
EXPLAIN THAT the higher the moisture content of wool, the lower the glass transition temperature.

- Wool at normal moisture content (12–15%) has a Tg ~ 60–70°C
- Wool at normal moisture content behaves like a glassy material at room temperature.
- At ~25% moisture, the Tg of wool is around room temperature (25ºC)
- The Tg of wet wool is below room temperature
- The Tg of dry wool is very high (>160ºC).

EXPLAIN THAT the method used to measure the glass transition must ensure the moisture content of the wool does not change during the measurement process (i.e. the wool sample must be sealed).

Because it affects the glass transition temperature of the wool, the moisture content of wool will determine :

- the success of many processing operations.
- the performance of wool products during wear.



NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding. The facilitator notes below will guide you as to the recommended time to run the animation.*

EXPLAIN THAT, as mentioned earlier, melting point refers to the temperature at which crystalline matter within a material changes completely from a solid to a fluid or rubbery material. Only crystalline or semi-crystalline materials (e.g. wool) have melting points. The crystal structure is the part of the polymer that melts.

PLAY THE ANIMATION as you explain that the transition occurs over a temperature range depending on the size of the crystallites in the crystalline regions.

EXPLAIN THAT the behaviour of a semi-crystalline polymer is shown on the slide of a trace obtained using a differential scanning calorimeter**.**

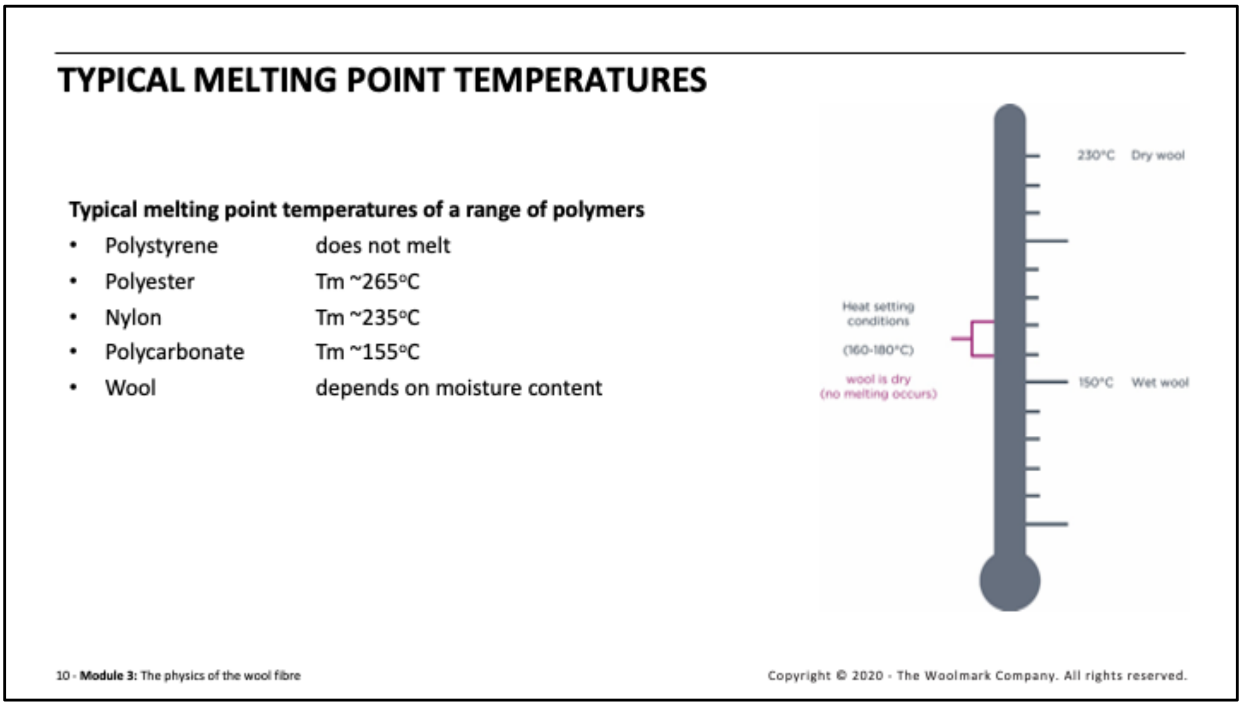
INDICATE THAT when many textile fibres melt, if unconstrained, they will contract significantly. This is called supercontraction. Observing the contraction allows the melting temperature to be measured.

EXPLAIN THAT this will be illustrated further on in this module.

INDICATE THAT the techniques used to measure the melting point of a polymer are similar to those used to measure glass transition temperature (including differential scanning calorimetry as shown on the slide).

REINFORCE THAT:

- glass transition is a change in the non-crystalline regions of a polymer.
- melting is a change in the crystalline regions of a polymer.



REFER participants to the typical melting point temperatures (Tm) of common textile polymers listed on the slide.

NOTE the typical melting point temperatures of semi-crystalline fibres are much higher than their glass transition temperatures.

EXPLAIN THAT as discussed earlier, non-crystalline materials, like polystyrene, do not have melting points as it is the crystal structure of the polymer that melts.

POINT OUT the melting temperature of wool is not specified on the slide because it varies according to the moisture content of the wool.

EXPLAIN THAT wool's crystalline regions will melt at around **230°C if the fibre is dry**. At this temperature the fibre will decompose.

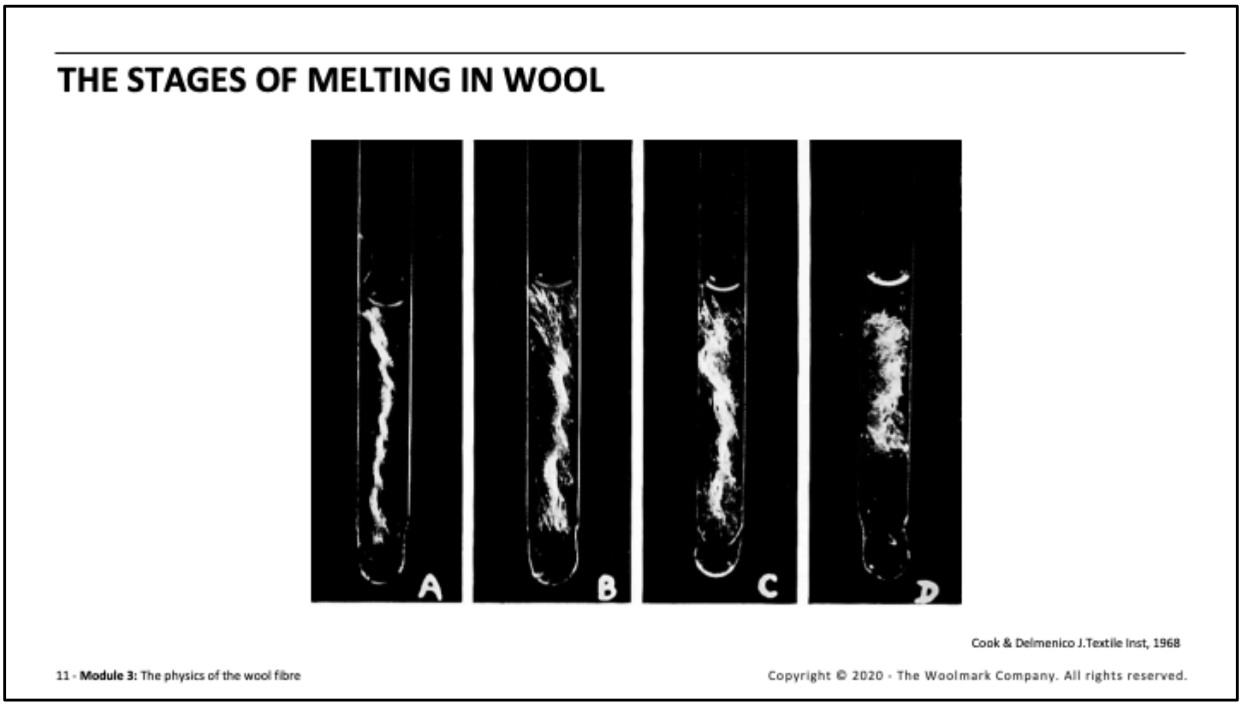
Wool's crystalline region will melt at around **150°C if the fibre is wet**.

EXPLAIN THAT the temperature at which wool melts chemically damages the fibre whether it is wet or dry.

POINT OUT that under heat setting conditions (160–180°C), wool is dry, so no melting occurs. This explains why wool does not melt during processing — unless the processor gets it wrong!

REINFORCE THAT when wool fibres melt:

- they supercontract — the unconstrained fibres (and yarn) shrink
- there is a significant change in the handle (feel) and appearance of the product
- the handle becomes harsh.

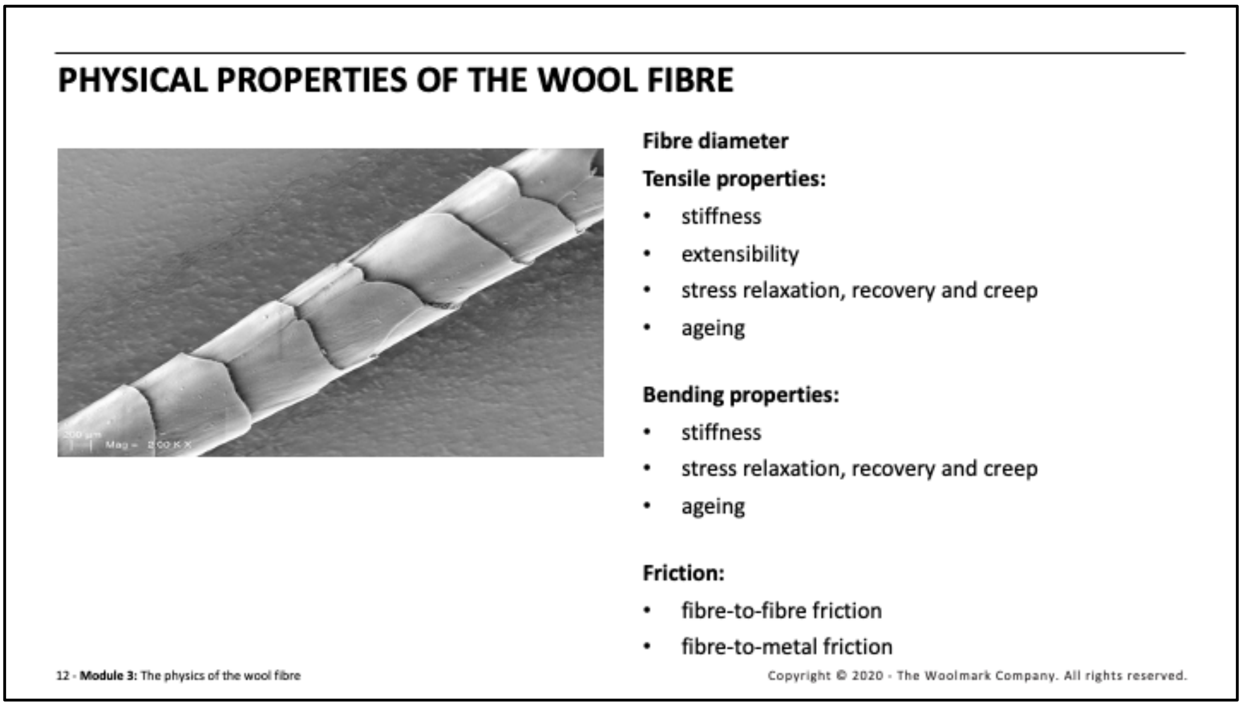


INDICATE THAT the micrographs shown on the slide show the stages in the melting and super contraction of wool.

A. A small piece of wool yarn in placed is a melting point tube containing water.
B. The tube is sealed so water vapour cannot escape and pressure can build inside the tube.
C. At around 150^{o}C the fibres contract, which is seen as a shortening of the yarn.
D. This is super contraction of the wool fibre.

EXPLAIN THAT the melting point of wool can also be measured using differential scanning calorimetry.

NOTE THAT you will now move on to cover the physical properties of the wool fibre as you transition to the next slide.



REVIEW THAT as discussed in previous topics, wool fibres consist of a range of components and behave like a composite material with a number of different physical properties.

INDICATE THAT the key physical properties of wool fibres that are important during processing are outlined on the slide and in the Participant Guide.

NOTE THAT the expression of these properties is influenced by the moisture content of the fibre.

BRIEFLY REVIEW the properties of wool listed below and indicate that each property will be covered in more detail in the following slides.

Fibre diameter

- The 'thickness' of the fibre measured in micrometers (µm —microns)

Tensile properties

- Stiffness — measured as the force required to stretch the fibre.
- Extensibility — the amount the fibre extends under load.
- Stress relaxation — the decay in the force required to hold the fibre at constant extension.
- Stress recovery – the amount the fibre recovers when the extension load is released.
- The rate of extension when under constant tensile load (creep).
- The effect of ageing.

Bending properties

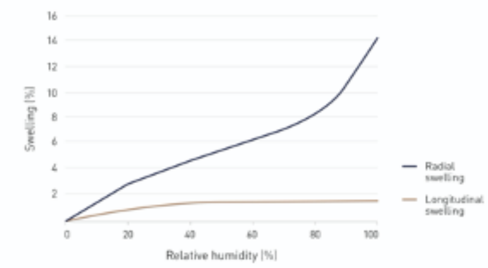
- Stiffness — the load to 'bend' the fabric.
- Stress relaxation — the decay on the load required to hold a fibre bent.
- Recovery – the extent to which fibres recover when the bending couple is removed.
- The creep or increase in bending strain when the load is maintained.
- The effect of ageing

Friction

- Fibre-to-fibre friction
- Fibre-to-metal friction

FIBRE DIAMETER

	MERINO WOOL	COTTON	SYNTHETICS
Typical mean fibre diameter (µm)	17–22	10 –14	8 –22
Coefficient of variation (%)	20–25	20 –25	5 –8



The anisotropic swelling of the wool fibre

13 - **Module 3:** The physics of the wool fibre

REMIND participants that the diameter of wool is measured as the mean fibre diameter (MFD), the standard deviation and coefficient of variation in the diameter (CVD).

As discussed in *Module 1 — Wool and other animal fibres*, the MFD of animal hair varies considerably between species and breed:

- Human hair = 45–55µm
- Corriedale wool = 27µm
- Merino wool = 17–22µm
- Cashmere = 16µm

INDICATE THAT as illustrated in the table shown on the slide, wool as a textile fibre suffers from an important disadvantages relative to its competitors — it is relatively coarse.

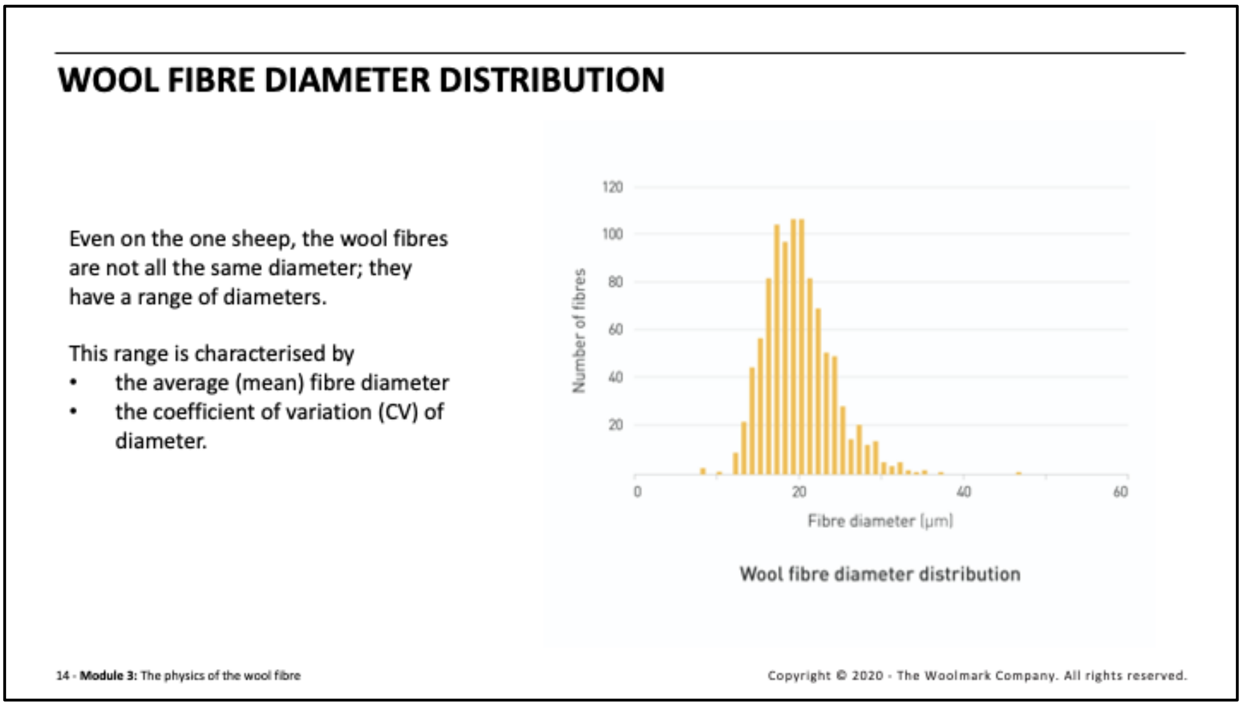
Even the finer sectors of the clip remain somewhat coarser than their competitors, cotton and man-made fibres, both typically having fibre diameters closer to 10–15µm.

EXPLAIN THAT the major driver for wool to become finer has been the trend for lighter-weight fabrics during the latter part of the previous century. For this reason wool fibre diameter continues to be the most important characteristic from the point of view of both quality and commercial value.

REMIND participants that:

- the diameter of wool fibres increases at it adsorbs moisture
- the greatest swelling occurs in the diameter — ~16% from dry to wet (radial swelling)
- the fibre swells ~1% in length from dry to wet (longitudinal swelling).

NOTE THAT this phenomenon (whereby the swelling of the wool fibre differs in magnitude according to the direction of measurement) is called ‘anisotropy’ swelling and is illustrated in the figure on the slide.



REFER participants to the graph on the slide, which demonstrates how the diameter of the fibres within a singe sample of wool varies across a wide range.

INDICATE THAT even on the one sheep, the wool fibres are not all the same diameter, there is a range of diameters.

EXPLAIN THAT the distribution of fibre diameters found in a sample of wool can be measured using:

- Laserscan machinery
- OFDA instruments
- microscopic measurement.

POINT OUT that the distribution of fibre diameters for natural fibres is much greater than that of synthetic fibres, which are spun in a spinneret.

NOTE: The mean fibre diameter (MFD) is an average, not an indicator, for all fibres in the sample.

EXPLAIN THAT the so-called the 'coarse edge' (percentage of fibres >30µm) has an important role in the skin comfort associated with wool products.

'Prickle' in wool products is normally associated with the coarse edge. The degree of prickle associated with a garment depends to a large extent on:

- the structure of the garment
- the conditions of wearing
- the sensitivity of the wearer.

NOTE THAT the sensations of 'prickle' and 'itch' are not fibre specific and can be induced equally by, for instance, acrylic fibres of sufficient diameter.

Instruments have been developed to measure the 'prickle factor' of fabrics (such as the wool comfort meter).

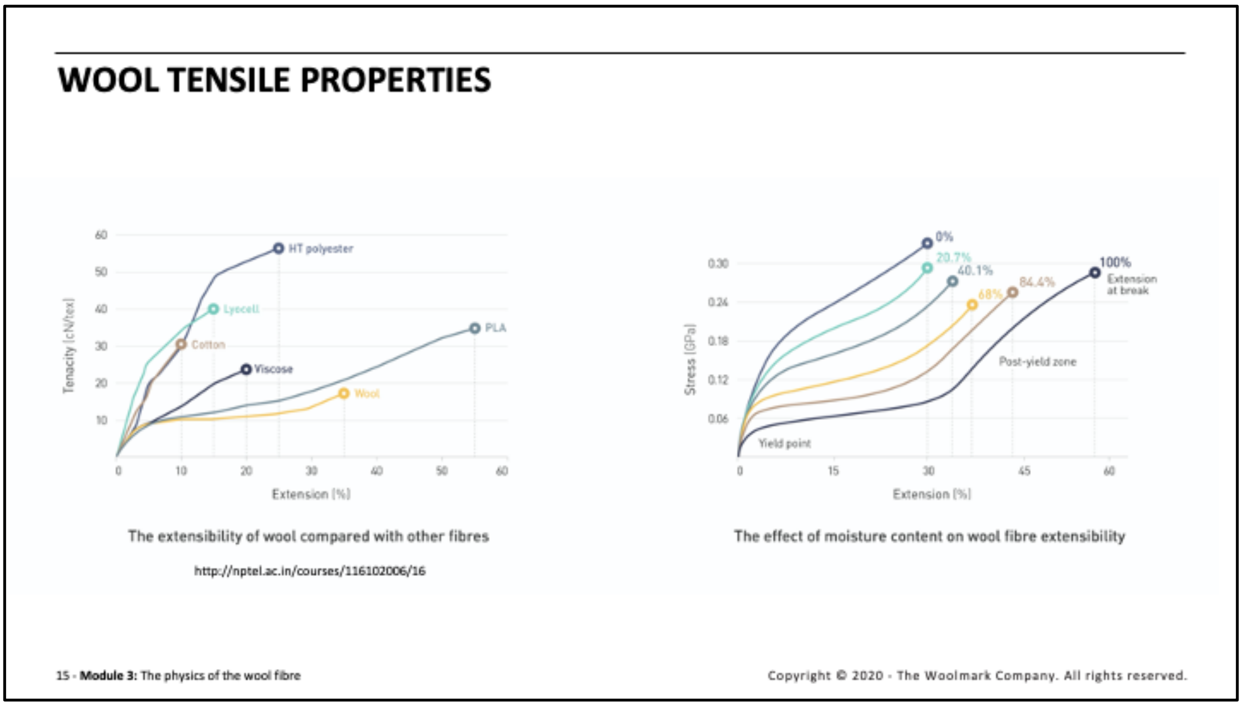
DEMONSTRATION OF PRICKLE FACTOR

Resources required:

- *coarse 'prickly' fabric*
- *fine 'soft' fabric*

ASK *for two participants to come forward, each placing one of the fabrics on their forearms and describing to the group how they feel before returning to their seats.*

ENCOURAGE *other participants to come and explore the fabrics after the lecture if they are interested in feeling the comparison.*



EXPLAIN THAT you will now move on to discuss the tensile properties of wool.

OUTLINE THAT tensile properties indicate how a material will react to forces being applied in tension.

Several of the tensile properties of wool are important for aspects of its performance as a textile:

- modulus (stiffness)
- extensibility
- stress relaxation and recovery
- creep
- ageing

EXPLAIN THAT the tensile properties of wool fibres are complex and involve distinct types of behaviour, including:

- an initial stiff response
- yield response (where the fibre extends more easily).

INDICATE THAT while wool is not as strong as many of its competitors, wool fibres are comparatively extensible (as shown the slide).

EXPLAIN THAT, like other properties, the ability of the fibre to extend (stretch) depends on its moisture content (as also shown on the slide).

Increasing the moisture content:

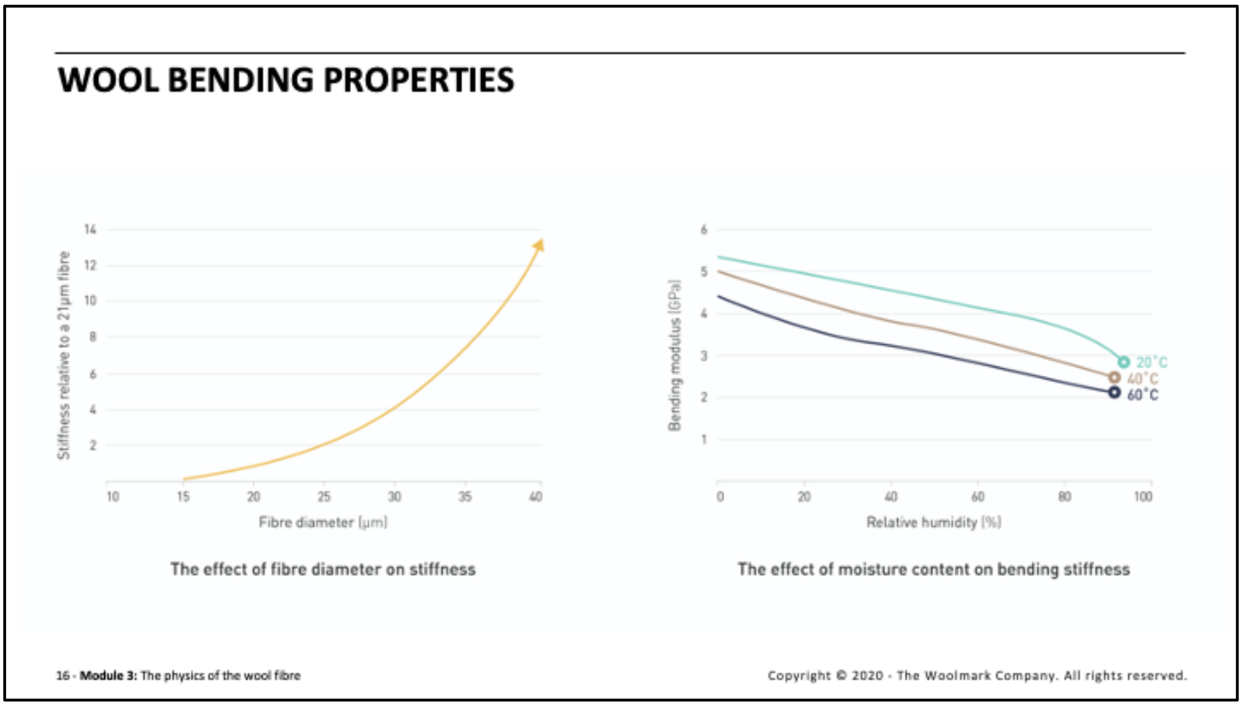
- 'plasticises' the fibre
- reduces the initial modulus (stiffness)
- reduces the stress at the yield point
- reduces the extension of the yield zone
- increases the extension on the post-yield zone
- increases the extension at break.

NOTE: The load at break is not greatly affected by the moisture content

EXPLAIN THAT during fibre processing, dry wool fibres can be extended beyond the initial 'stiff region' and in some cases to the breaking point.

If the fibres are very dry the extension at break is smaller than that in properly conditioned or 'wet' fibres. This reinforces the need to properly condition wool during processing operations.

EXPLAIN THAT after the wool has been processed to fabric or garment, it is rare that wool fibres are extended beyond the initial stiff region.



EXPLAIN THAT bending properties indicate how a material will react to bending forces. Several of the bending properties of wool are important for aspects of its performance as a textile, such as:

- bending rigidity
- flexibility
- stress relaxation and recovery
- creep
- ageing.

NOTE THAT these concepts will be covered in the next slides.

INDICATE THAT this slide demonstrates the effect of fibre diameter on the bending rigidity of wool fibres. The greater the diameter of the fibre (i.e. the broader the micron), the 'stiffer' or more rigid the fibre is. The stiffness of the fibre (and ultimately the fabric) in bending, varies as the fourth power of the diameter.

The stiffer the fibre; the stiffer the fabric. This is relevant when choosing which type of fabric is most suitable for a particular application.

DEMONSTRATION — FIBRE DIAMETER AND STIFFNESS

Resource required:

- *thin knitting needle*
- *thick knitting needle.*

SELECT *a participant to help with the demonstration.*

HAND *the knitting needles to the participant and ask them to gently bend the thicker needle and then gentle bend the thinner needle, taking care not to break the needles.*

ASK *the participant to describe which needle was easier to bend and reinforce, that, like the knitting needles, the finer the fibre, the easier it is to bend.*

EXPLAIN THAT this slide also demonstrates the effect of moisture content on the bending rigidity of wool fibres. The lower the moisture content; the stiffer the fibre. Water plasticises the fibre, so the bending rigidity of the fibre is reduced at high moisture content.

It is also worth noting that stiffness is affected by temperature — the lower the temperature; the stiffer the fibre.

DEMONSTRATION — MOISTURE AND STIFFNESS

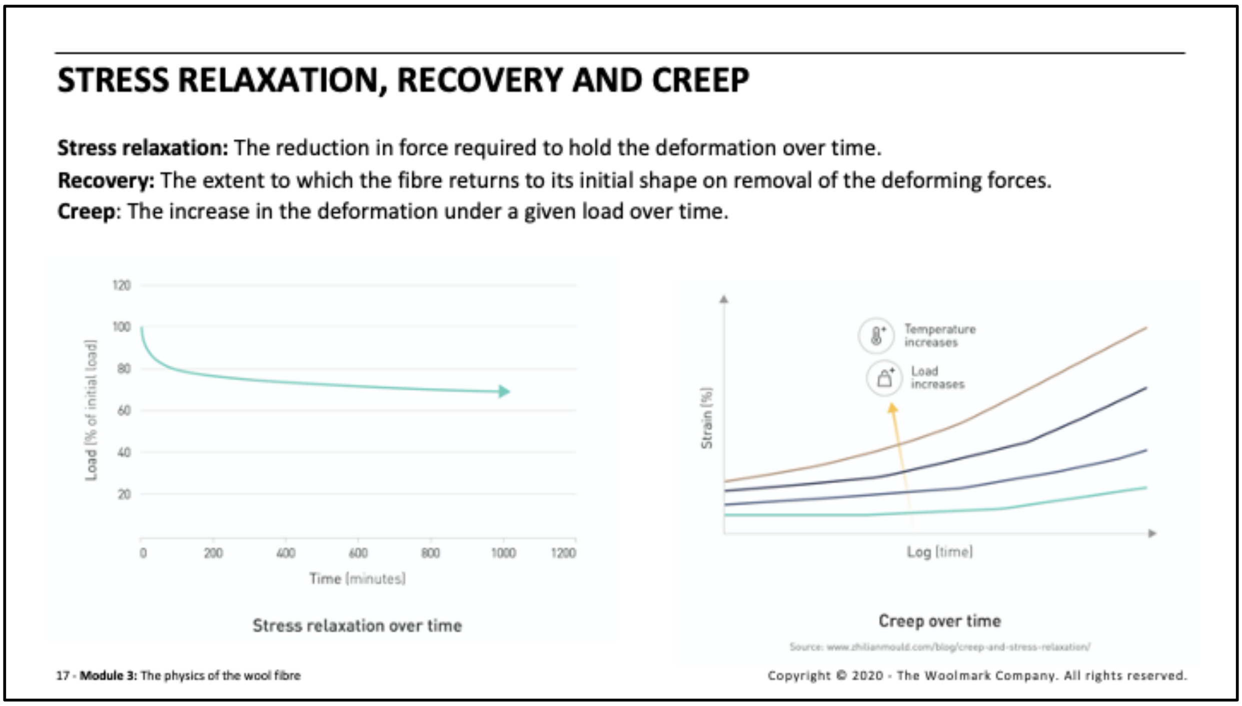
Resource required:

- *wet noodle (e.g. udon noodle)*
- *dry noodle (e.g. spaghetti or rice noodle).*

ASK *participants to suggest how the noodles illustrate how moisture content impacts on bending rigidity.*

ACKNOWLEDGE RESPONSES

HOLD UP *each noodle and indicate that the wet and dry noodles illustrate how moisture content impacts on bending rigidity in the same way as for wool fibres.*



EXPLAIN THAT many materials undergo 'stress relaxation' — the reduction in force required to hold the deformation over time as illustrated on the slide. Following removal of this force, the recovery relates to the extent to which the fibre returns to its initial shape.

EXPLAIN THAT such materials also undergo creep — the increase in deformation under a given load with time.

POINT OUT that creep occurs when a wool garment, such as a sweater or cardigan, stored on a coathanger develops 'coathanger shoulders' (i.e undesired deformations).

INDICATE THAT materials that stress relax rapidly have high creep and poor recovery. The rate of stress relaxation and creep depend on temperature and composition.

NOTE: The glass transition temperature (Tg) of a fibre is associated with a rapid increase in stress relaxation — when a material exceed the Tg the the rate of stress relaxation increases more rapidly.

By plotting the change in the rate of creep under load with temperature, the glass transition temperature can also be measured.

DEMONSTRATION — RECOVERY AND CREEP

Resources required:

- *memory foam*
- *rubber ball (e.g. tennis ball).*

SQUEEZE THE *mass of memory foam and release.*

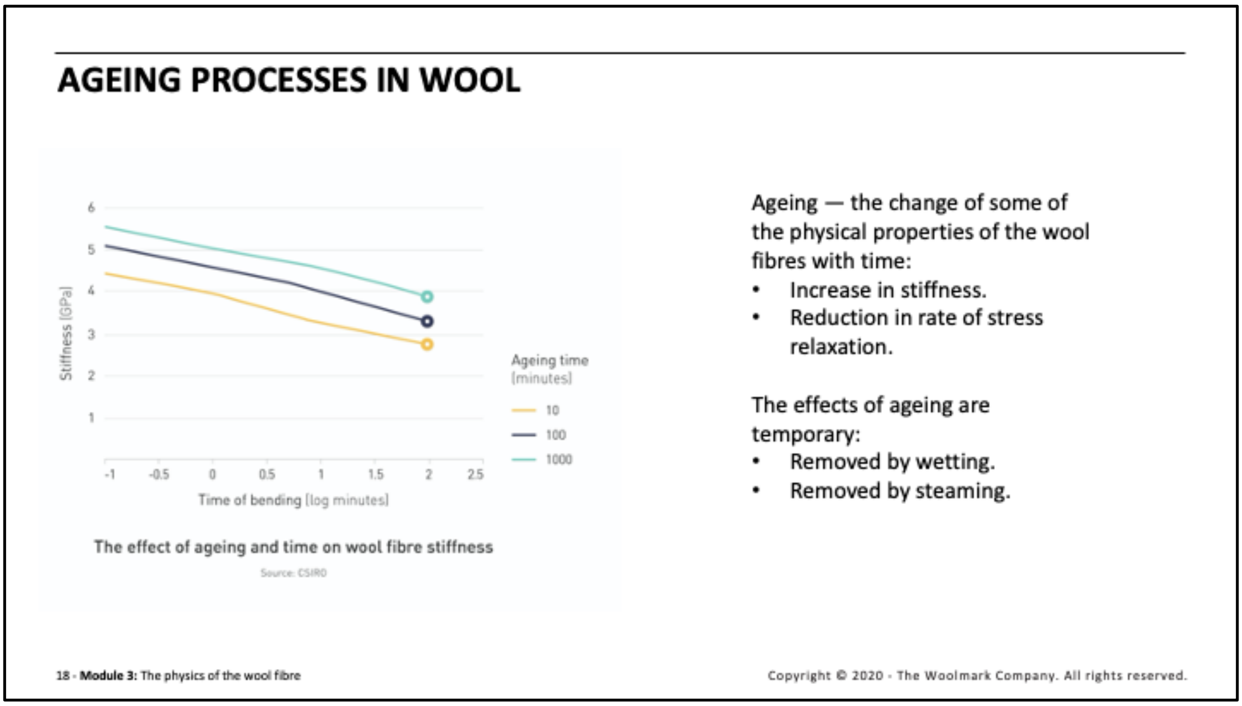
EXPLAIN THAT *the memory foam has 'high' stress relaxation — when you squeeze it, it deforms easily, but is slow to 'recover'.*

EXPLAIN THAT *the memory foam also creeps under load — when you push your finger into it, it penetrates the mass quickly.*

PRESS *the rubber ball to form a depression and then release the pressure on the ball.*

EXPLAIN THAT *the rubber ball has a 'low' stress relaxation — when you press it, it is difficult to bend and when the pressure is released the rubber ball quickly recovers.*

NOTE: *Stress relaxation occurs both in the tension and bending of wool.*



EXPLAIN THAT all amorphous (non-crystalline) and semi-crystalline materials 'age'.

Ageing is the term used to describe the change of some of the physical properties of wool fibres with time, such as stiffness and rate of stress relaxation.

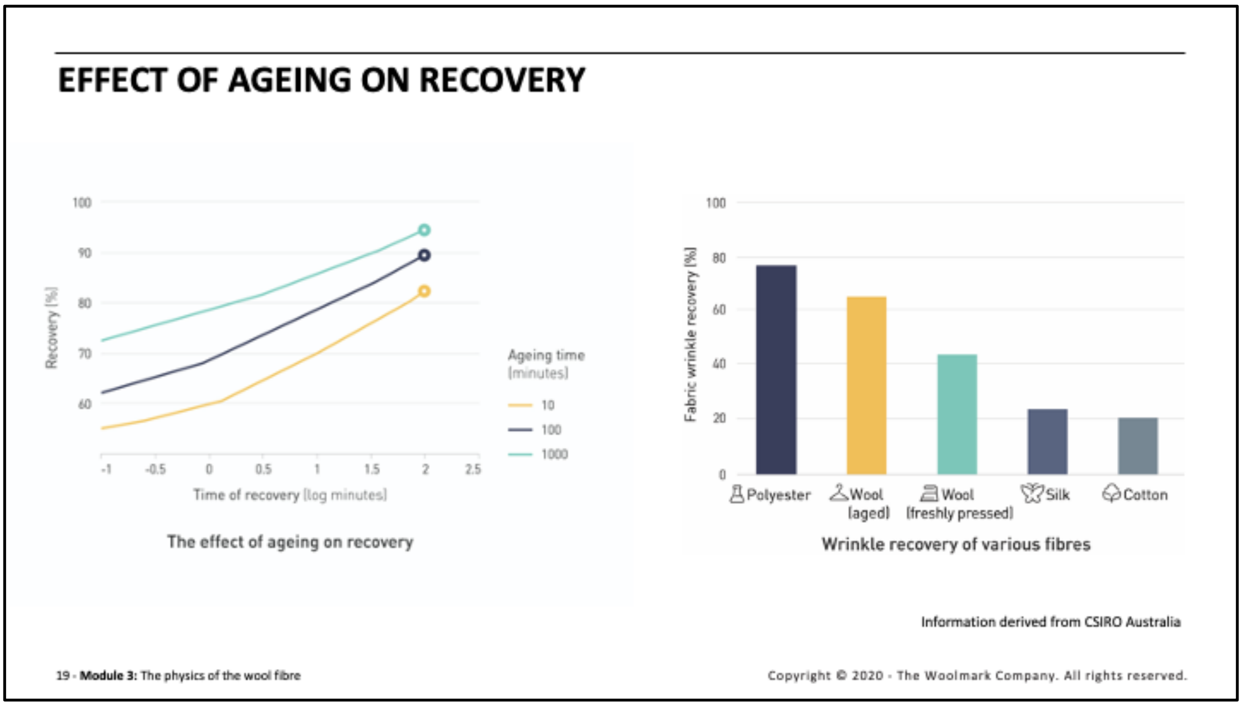
Ageing is also associated with a reduction in the free volume of the non-crystalline part of materials with time.

EXPLAIN THAT the figure in the slide shows:

- wool fibres stress relax with time.
- the fibre is stiffer the longer it is aged before deformation.

NOTE THAT the effects of ageing are temporary. Materials can be 'de-aged' (i.e. the effects of ageing are removed).

EXPLAIN THAT wool can be de-aged by steaming or wetting.



EXPLAIN THAT this slide shows the recovery of aged wool from bending.

INDICATE THAT the figure on the left shows that when the deforming (bending) force is removed the fibre slowly recovers its original shape. The longer the fibre is aged before deformation, the better it recovers after bending (or other deformations). The impact is that aged wool garments have better wrinkle recovery than those that have been dry cleaned or washed.

EXPLAIN THAT washing or dry cleaning a wool garment has the effect of 'de-aging' the garment. If it is worn immediately the garment will wrinkle more severely than if it was allowed to 'rest' in a cupboard for some time before wear.

INDICATE THAT the right-hand figure, illustrates that a well-aged wool product will resist wrinkling almost as well as a polyester product, which has excellent wrinkle recovery. A non-aged wool garment (e.g. freshly washed or pressed) will wrinkle more than polyester or an aged wool garment, but will not wrinkle as badly as a cotton garment.

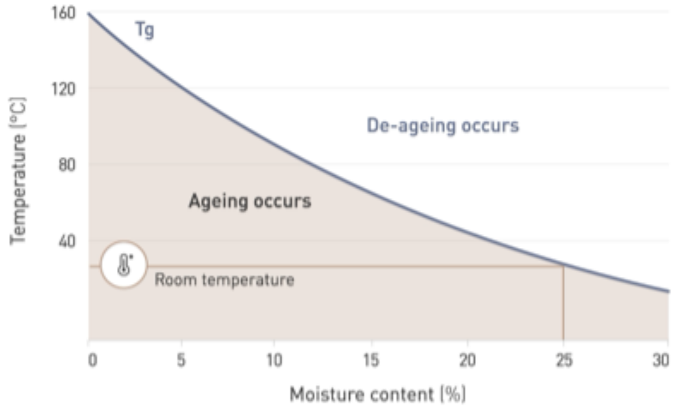
EXPLAIN THAT the amount of time required to age wool depends on the conditions of wearing (e.g. wool wrinkles more in hot, humid environments).

BEFORE PROCEEDING to the next slide:

ASK *participants to suggest why do steaming and wetting processes de-age wool?*

ASK *participants to suggest why wool wrinkles more in hot humid environments?*

EFFECTS OF GLASS TRANSITION ON AGEING



The effect of glass transition on ageing in wool

20 - **Module 3:** The physics of the wool fibre

NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding.*

PLAY THE *animation as you explain that ageing and de-ageing of materials are associated with their glass transition temperature (Tg).*

NOTE THAT ageing only occurs below the glass transition temperature as shown in the animation. De-aging occurs above the glass transition temperature (Tg).

REMIND participants that, as covered earlier in this module, and illustrated in the animation, the glass transition temperature (Tg) of wool depends on its moisture content. As the moisture content of wool increases, its glass transition temperature (Tg) drops.

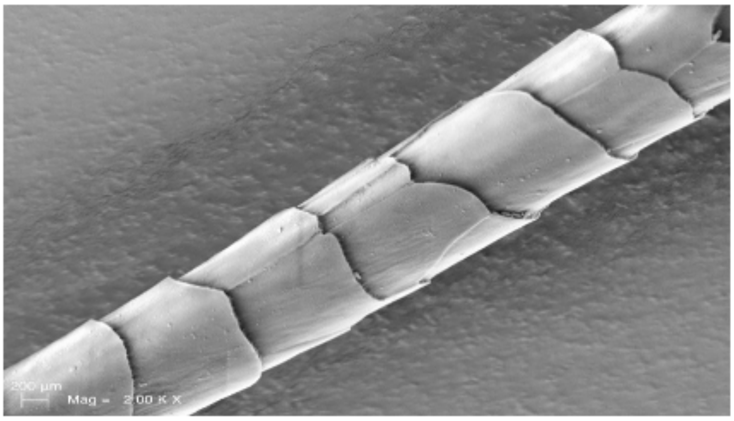
Applying a combination of heat and moisture to a wool fabric (such as occurs during the steaming or wetting processes) can take the fabric ‘above’ the glass transition temperature, effectively ‘de-aging’ the fabric and increasing its propensity to wrinkle.

Similarly, if a wool garment is exposed to both heat and moisture (e.g. when the wearer is perspiring on a hot day), it can cause the fabric to wrinkle. Wrinkling will be severe unless the fabric is allowed to recover above its Tg.

FIBRE-TO-FIBRE FRICTION — DIRECTIONAL FRICTIONAL EFFECT

Root to tip $\mu = 0.11$ →

← Tip to root $\mu = 0.16$



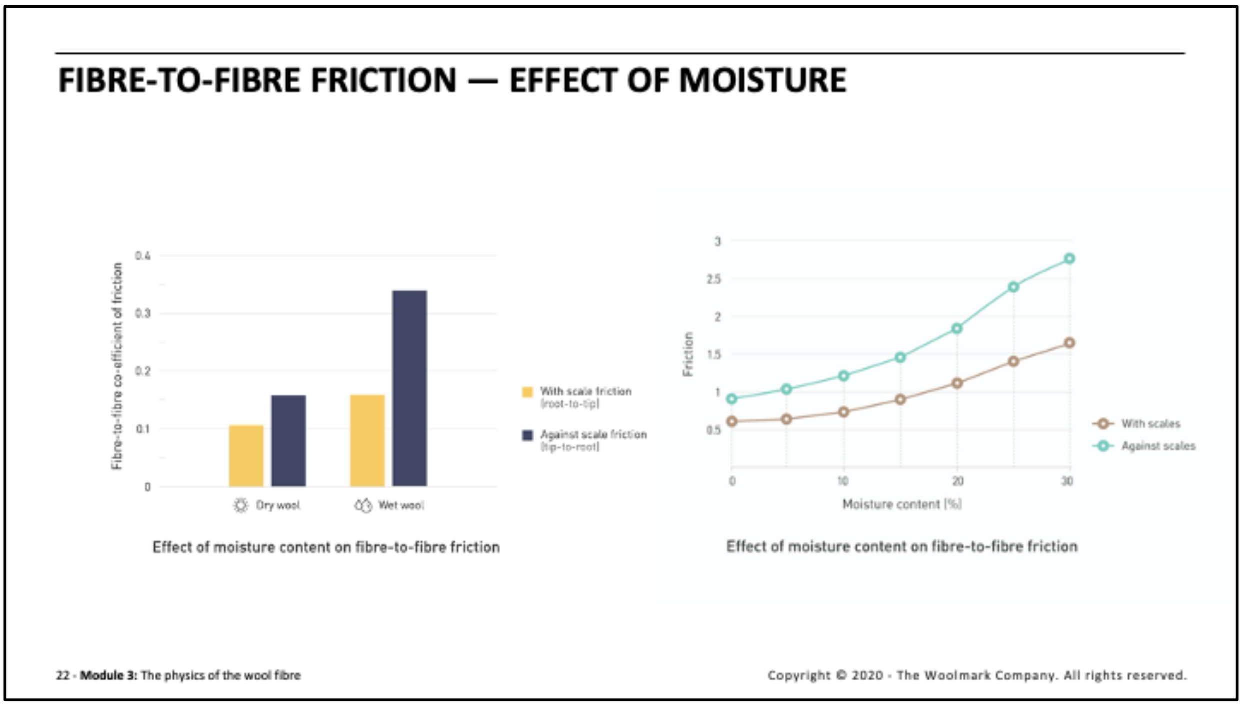
The directional frictional effect (DFE)

21 - **Module 3:** The physics of the wool fibre

EXPLAIN THAT wool, like all animal fibres, has unique frictional properties caused by the arrangement of the cuticle cells (scales) on the surface of the fibre.

NOTE THAT as explored during *Module 2: The structure of wool fibres,* and as illustrated on the slide, because the cuticle cells form a sloping ridge on the surface of the fibre, the friction caused by moving along the fibre from root to tip (with the direction of the scale), is less than the friction caused by moving along the fibre from tip to root (against the direction of the scale). The root-to-tip friction for ‘dry wool’ is usually around $\mu = 0.11$, whereas the tip-to-root friction for dry wool is usually $\mu = 0.16$.

REMIND participants the difference between the root-to-tip friction and tip-to-root friction two is known as the directional frictional effect (DFE).



***NOTE TO FACILITATOR:** The bar chart on this slide is animated to enhance participant understanding. Allow the animation on the slide to play before you explain the effect of moisture content on fibre-to-fibre friction.*

EXPLAIN THAT the left-hand graph on the slide shows the difference in the 'root-to-tip' friction and 'tip-to-root' friction between wet and dry wool and how the differential frictional effect (DFE) is higher when the fibre is wet.

NOTE THE difference in wet and dry friction of wool is thought to be a result of the swelling of the cuticle cells.

EXPLAIN THAT as the cuticle cells become more pronounced in water, this increases the:

- friction between the fibres,
- difference between the 'root-to-tip' friction and 'tip-to-root' friction (i.e. the DFE).

DRAW participants attention to the right-hand graph as you explain that the increase in friction is gradual as the regain (moisture content) increases.

EXPLAIN THAT the exocuticle is highly crosslinked and would not be expected to swell significantly with increased moisture content of the fibre. The endocuticle on the other hand is lightly crosslinked and would swell with moisture lifting the scales edges which remain relatively hard.

NOTE THAT these frictional properties also occur between fibre and metal, not just between fibres. Both fibre-to-fibre and fibre-to-metal friction are important in wool processing.

FIBRE-TO-FIBRE FRICTION — EFFECT ON FABRIC RECOVERY

REMIND participants that in *Module 2 Structure of the wool fibre* the effect of fibre-to-fibre friction on fabric handle was introduced.

REITERATE that as yarn (or fabric) is deformed (e.g. creased or folded), fibres move relative to adjacent fibres and the level of friction between these fibres affects this movement.

- If the friction is low (e.g. in undamaged wool) the fibre-to-fibre movement is relatively easy, the yarn or fabric deforms easily while retaining a soft 'feel' or 'handle'.
- If the friction is high (e.g. in damaged wool) the relative movement of fibres is more difficult and the deformed fabric feels harsher.

EXPLAIN THAT fibre-to-fibre friction also affects the 'recovery 'of fabrics from imposed deformation (e.g. wrinkling). When deformed fabrics are released, the fibres try to return to their previous position.

- If the friction is low (e.g. in undamaged wool) the return movement is relatively easy, the fabric recovers easily and residual deformation (i.e. wrinkles or creases) is minimal.
- If the friction is high (e.g. in damaged wool) the movement is more difficult, the recovery of the fabric is impeded, and the residual deformation (i.e. wrinkles or creases) is greater.

***ASK** participants to stand and observe their clothing for signs of wrinkling.*

***ASK** participants to raise their hand if they noticed wrinkles or creases from sitting during the lecture.*

***ACKNOWLEDGE RESPONSES** and encourage participants to return to their seats.*

EXPLAIN THAT during wear, wrinkling involves both:

- stress relaxation of the fibres
- frictional interaction between fibres.

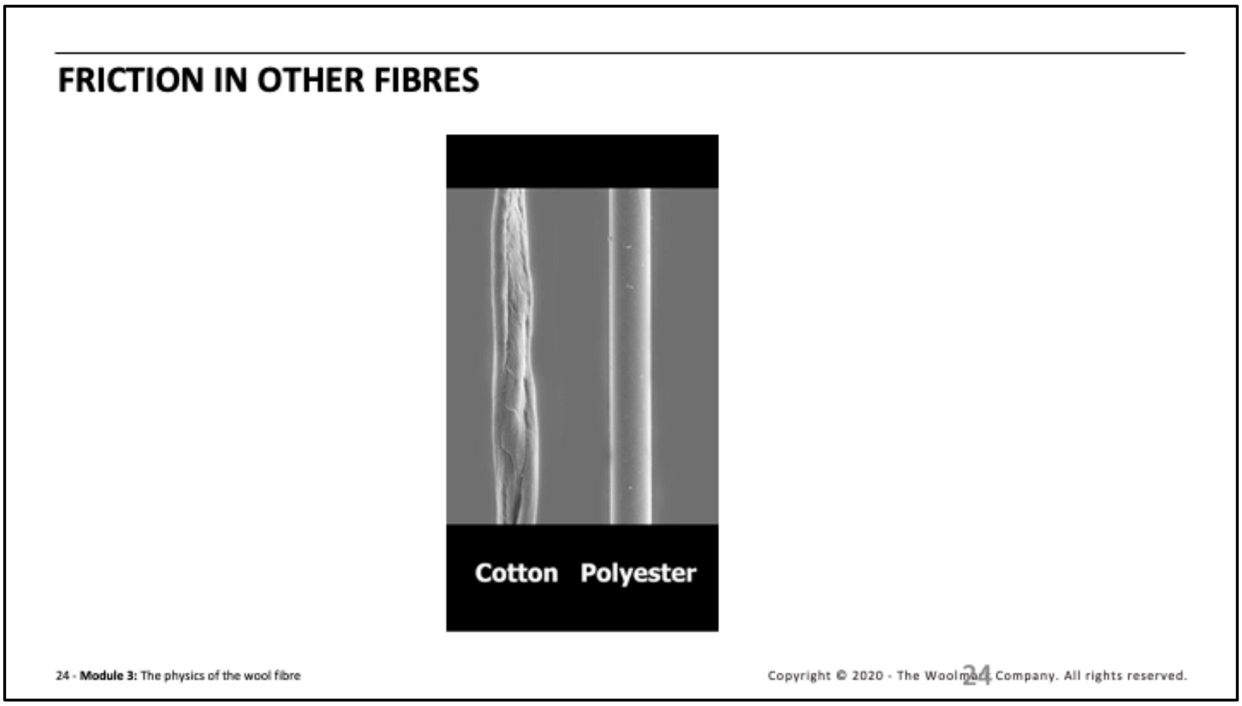
EXPLAIN THAT if the deformation occurs over an extended period, (e.g. sitting on a plane or in a car for a long journey) then fibre stress relaxation dominates recovery (i.e. the wrinkles will remain in the fabric unless conditions such as humidity and temperature change).

BRIEFLY mention that deformation over an extended period during wear in normal conditions can impart 'cohesive set' to wool fabrics. The concept of 'cohesive' and 'permanent' set and the conditions under which they occur will be explored in detail in *Module 5 The setting of the wool fibre*.

EXPLAIN THAT if the deformation is fast (e.g. while playing sport) the fibre stress relaxation is small and recovery is dominated by frictional effects within the fibre.

POINT OUT that in most wear situations, because the fibre-to-fibre friction of wool low compared to other fibres (e.g. linen), the frictional contribution to the wrinkling of wool fabrics is low.

NOTE: Cotton fibres can have high fibre-to-fibre friction so the frictional component of wrinkling in cotton fabrics can be high.



EXPLAIN THAT the frictional properties of fibres vary according to their source material and the effects of processing.

DRAW participants' attention to the image on the slide as you explain that the friction between cellulosic (plant-based) fibres (e.g. cotton) depends on whether the fibre is raw or has been processed.

Raw fibre has low fibre-to-fibre friction due to presence of natural waxes on the surface of the cotton fibre, however there is no directional frictional effect (DFE).

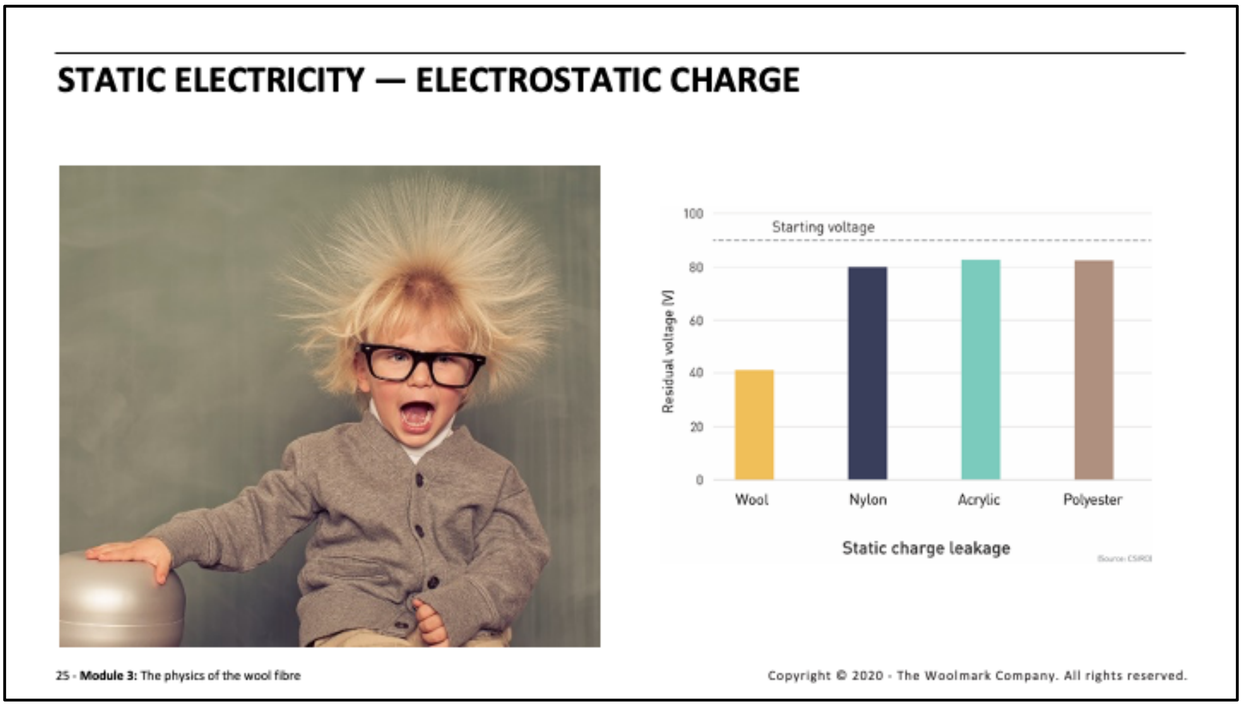
EXPLAIN THAT fabric finishing removes these residual waxes, increasing fibre-to-fibre friction.

Lubricants and softeners also reduce fibre-to-fibre friction resulting in softer fabric handle.

DRAW participants'' attention to the image of the polyester fibres as you explain that untreated synthetic fibres (e.g. nylon and polyester) generally have high fibre-to-fibre and fibre-to-metal friction, however there is no directional frictional effect (DFE).

***SUMMARISE** by explaining that friction depends on the presence of lubricants or finishes:*

- *Clean nylon — very high friction*
- *Clean polyester — lower friction.*



DEMONSTRATION — ELECTROSTATIC CHARGE

Resources required:

- *Balloon (blown up)*

ASK *for a participant with medium-length hair to assist you with the demonstration by rubbing the blown-up balloon against their hair and then removing the balloon slowly to demonstrate static electricity.*

ALLOW THE *participant to resume their seat.*

EXPLAIN THAT static electricity (electrostatic charge) is produced when two bodies touch, rub together and then separate from each other.

The value of the charge varies according to the:

- electrical properties of the materials (most textile materials are poor conductors of electricity, although conductivity increases with moisture content and conditioning)
- external influences (e.g. relative humidity in the workplace).

DRAW ATTENTION to the difference between the static charge of various textiles on the slide.

EXPLAIN THAT when fibres are processed during manufacture, static electricity is generated. The electrostatic charge can become so high as to make the fibres difficult to control.

Conditioning by storing semi-finished products helps to reduce the build-up of static, but requires time and is unsuitable for economic reasons.

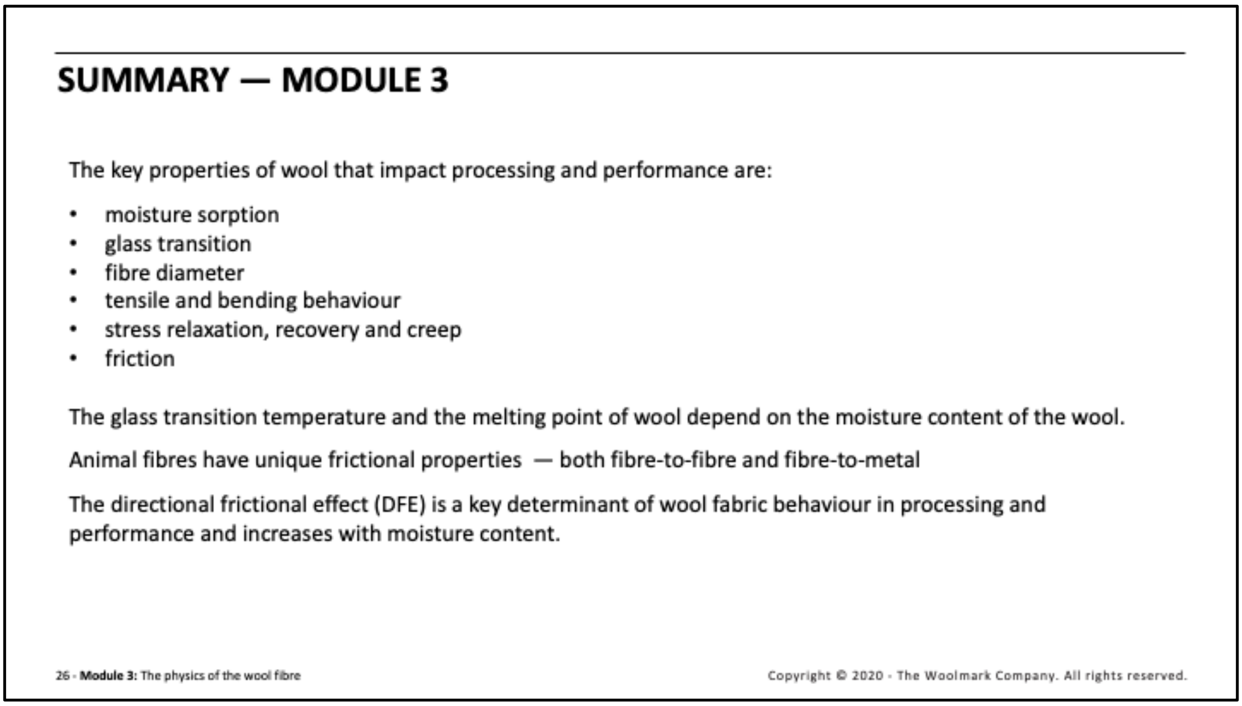
EXPLAIN THAT the two major methods used in modern textile manufacture are:

- to control the ambient air humidity by regulating the air conditioning
- to use antistatic processing aids.

NOTE THAT the use of antistatic processing aids is covered in detail in the unit of the Woolmark Wool Education Course *Worsted top-making*.

EXPLAIN THAT left uncontrolled, static electricity will cause:

- excessive waste during processing
- excessive 'fly' in the air
- numerous roller laps
- yarns sticking (in warping)
- hairy yarns and fabrics.



SUMMARISE the module by briefly revising the key properties that impact on the processing and performance of wool:

- the moisture sorption
- glass transition
- the diameter of the fibres (which are influenced by moisture content)
- the tensile and bending behaviour (which depend on moisture content)
- the stress relaxation, recovery and creep.

REMIND participants that the 'melting' point has no effect on processing and performance.

REINFORCE that the 'glass transition' affects the physical properties of the fibre (such as stress relaxation and ageing) and the glass transition temperature (Tg) and the melting point of wool depend on the water content of the wool.

REITERATE that ageing is the change in the properties of wool fibres with time:

- Ageing occurs below the Tg.
- De-aging occurs above the Tg.

REVIEW the fact that animal fibres have unique frictional properties — both fibre-to-fibre and fibre-to-metal.

REINFORCE that directional frictional effect (DFE) is a key determinant of fabric behaviour in processing and performance and is greater in wet wool than dry wool.

ASK *participants if they have any questions about the content covered in this module.*

ALLOW *time for questions and discussion before proceeding to the final slide and closing the lecture.*

INFORM participants of the time and location for the next lecture — *Module 4 The chemistry of the wool fibre* — and ensure they read through the relevant notes in their Participant Guides before attending the lecture.

ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in today's lecture.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

BEFORE participants leave ensure you have collected any samples distributed during the lecture.

MODULE 4

THE CHEMISTRY OF THE WOOL FIBRE

RESOURCES — MODULE 4: THE CHEMISTRY OF THE WOOL FIBRE

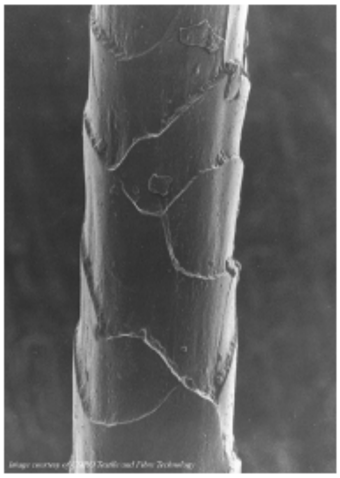
Contained in the *Wool fibre science* Demonstration kit you will find the following resources for use as you deliver **Module 4: The chemistry of the wool fibre**:

- plasma-treated fabric
- untreated fabric
- yellowed wool fabric
- untreated (normal) wool fabric.

WELCOME participants to Module 4 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The chemistry of the wool fibre*.

THE CHEMISTRY OF THE WOOL FIBRE

- An overview of the proteins and lipid materials that form wool
- An overview of the crosslinks between protein macromolecules
  - covalent
  - ionic
  - polar
  - non-polar
- Disulphide interchange
- The bonding of the surface lipid to wool
- The yellowing of wool in finishing



2 - **Module 4:** The chemistry of the wool fibre

EXPLAIN THAT as outlined on the slide, this module will provide an overview of the chemical components within the wool fibre, including:

- an overview of the proteins and lipid materials that form wool
- a description of the crosslinks between protein macromolecules and their impact on fibre properties, including
  - covalent
  - ionic
  - polar
  - non-polar
- disulphide interchange and its role in the setting processes in the fibre
- the chemistry of the wool structural components
- the bonding of the surface lipid to wool and its implications for wool ‘felt-resist’ treatment
- the causes of yellowing of wool.

INFORM participants that by the end of this module they will be able to:

- nominate the chemical components of wool fibre
- describe the four major categories of crosslinking that occur between protein chains within wool fibre and the relevance each to processing
- outline the effects of pH on fibre properties
- describe some of the causes of wool yellowing and its relevance to processing.

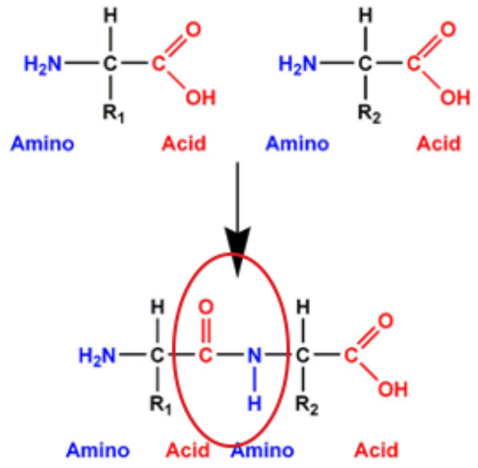
RESOURCES REQUIRED FOR THIS MODULE

- *plasma-treated fabric*
- *untreated fabric*
- *yellowed wool fabric*
- *untreated (normal) wool fabric.*

IN CHEMICAL TERMS — WHAT IS A PROTEIN?

A protein is a polymer:
- formed in nature
- combining the 22 naturally-occurring amino acids
- the link formed is an ‘amide’

The properties of proteins are determined by:
- the types of amino acids
- the sequence of the amino-acids
- the shape adopted by the protein molecule
    - linear
    - globular (coiled up)



3 - **Module 4:** The chemistry of the wool fibre

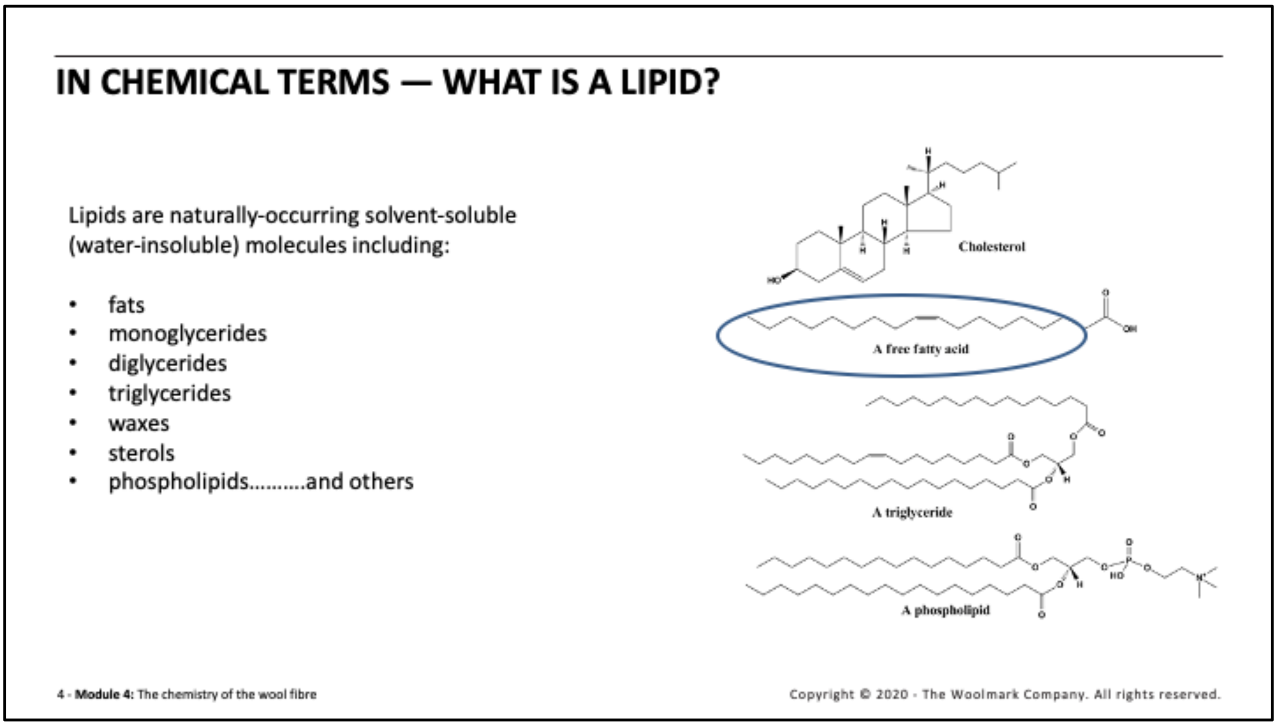
REVIEW WITH participants that proteins are polymers formed in nature by combining some, or all, of the 22 naturally-occurring amino acids.

EXPLAIN THAT the link formed between the amino acids is an amide bond.

The amide bonds joining the amino acids are sometimes called ‘peptide bonds’.

The protein chains formed by links of amino acids are also called ‘polypeptides’.

EXPLAIN THAT the properties of proteins are determined by:
- the types of amino acids combined in the macromolecule
- the sequence of the amino-acids along the polymer chain
- the shape adopted by the protein molecule
    - linear
    - globular (coiled).



INFORM participants that the other significant chemical components of wool are lipids, which were briefly discussed in *Module 2 The structure of wool fibres* when exploring the cuticle cells (scales).

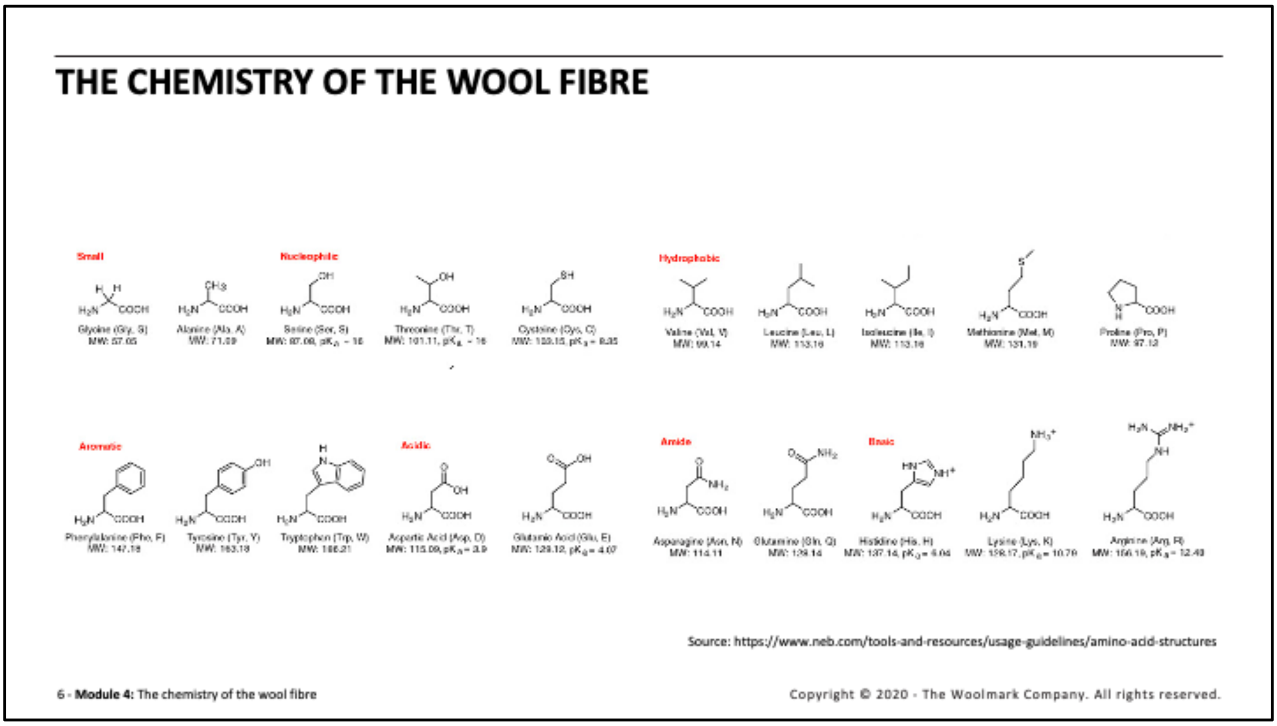
EXPLAIN THAT in chemical terms, lipids are naturally-occurring solvent-soluble (water-insoluble) molecules including:

- fats
- monoglycerides
- diglycerides
- triglycerides
- waxes
- sterols
- phospholipids……….and others.

REFER participants to the slide, which illustrates the chemistry of lipids. Make particular reference to the hydrophobic section of the free fatty acid is circled.

NOTE THE hydrophobic (water-resistant) sections of many of the lipids.

WELCOME participants to Module 4 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The chemistry of the wool fibre*.



DIRECT participants to the slide and explain that it shows a list of the amino acids found in proteins grouped into their types:

- small
- nucleophilic — will form associations with water molecules and other polar molecules. These are also called 'polar groups'. Nucleophilic groups will also react with 'electrophilic' groups on compounds introduced into the fibre.
- hydrophobic — do not like water.
- aromatic — contain benzene rings.
- acidic — have an acid side chain.
- amide – have an amide side chain, which can hydrolyse to give an acid side chain.
- basic — have a basic side chain.

DRAW participants attention to the relevant amino acid on the slide as you work your way through the following notes:

Aspartic acid and glutamic acid have a carboxyl (–COOH) side group. Under high pH (alkaline) conditions this side group can become ionised and negatively charged (carboxylate).

Lysine, histidine and arginine have an amine (–NH_2) side group. Under appropriate low pH (acid) conditions this side group can become ionised and positively charged (ammonium). Positively-changed ionic sites within wool provide excellent binding sites for wool dye molecules, all of which are negatively charged.

Phenylalanine has an aromatic ring side group, which is non-polar. There are also other amino acids in wool with non-polar side groups.

Cysteine and cystine
One of the most important amino acids is cystine because it forms crosslinks between adjacent protein chains (called 'disulphide bonds'). Disulphide bonds are formed during fibre growth by a process called 'keratinisation'.

These bonds make keratin fibres insoluble in water and more stable to chemical and physical attack than other types of proteins.

Cysteine has a sulphur side group. As indicated in the diagram on the previous slide, cysteine side groups tend to form a disulphide bond with other cysteine side groups. The amino acid in which the sulphur groups of cysteine form a disulphide bond is called 'cystine'.

Serine and threonine have a hydroxyl (–OH) side group. Hydroxyl groups are polar and capable of bonding to other polar molecules, such as water. All of the amino acids with polar side groups are hydrophilic (water loving) and can act as sites for association with adsorbed water.

Tryptophan is a highly reactive amino acid, which forms coloured products which is associated with the yellowing of wool in sunlight.

THE CHEMISTRY OF THE WOOL FIBRE

GROUP	OLD NOMENCLATURE	NEW NOMENCLATURE
Keratin intermediate filament	Type I — low sulphur	K1.n
	Type II — low sulphur	K2.n
Proteins in cortex associated with keratin intermediate filament	High sulphur	KAP1.n KAP2.n KAP3.n
	Ultra high-sulphur	KAP4.n KAP11.n
	High glycine/tyrosine Type II	KAP6.n
	High glycine/tyrosine Type I C2[#]	KAP7
	High glycine/tyrosine Type I F[#]	KAP8
Keratin proteins in cuticle	Ultra-high sulphur	KAP5.n
		KAP10.n

Each protein group contains a number of individual proteins designated by the number 'n'.
[#] indicates the two Type I proteins are not homologous.

Information derived from CSIRO Australia

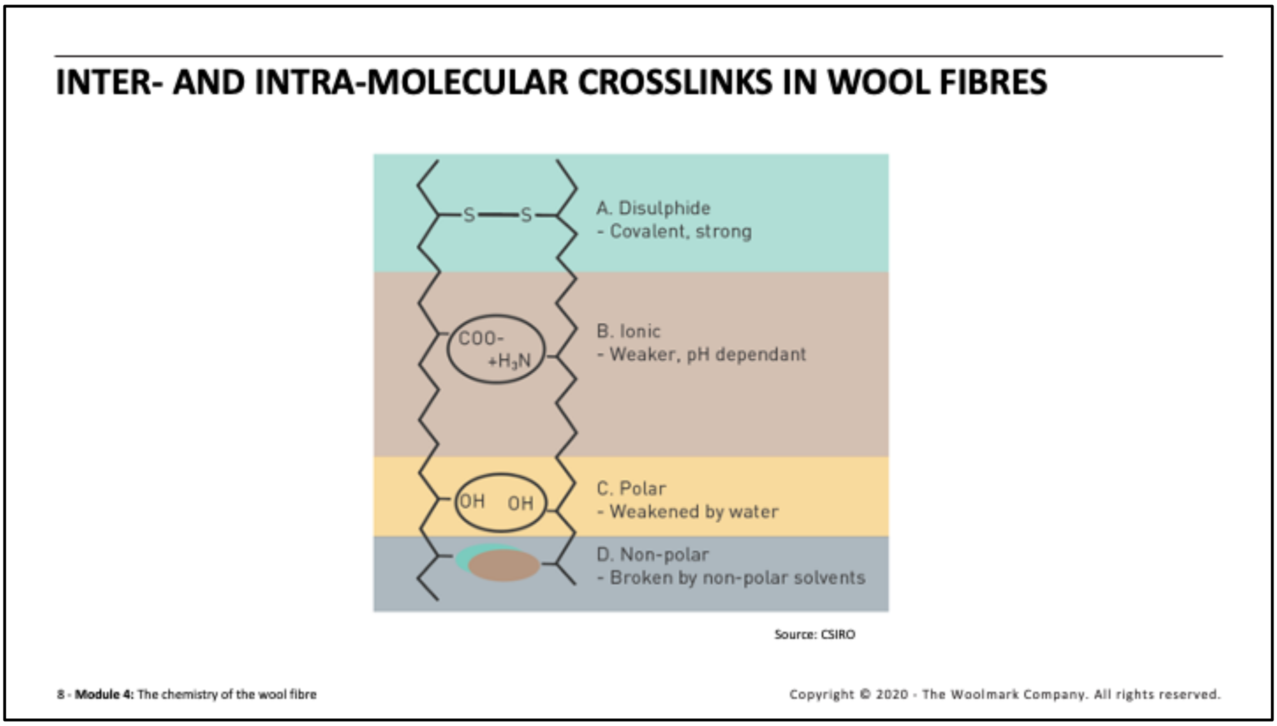
7 - **Module 4:** The chemistry of the wool fibre

EXPLAIN THAT although keratin proteins always contain disulphide bonds there are many different keratin proteins in the wool fibre (about 170).

INDICATE THAT these proteins are classified in groups and are given different designations, as shown on the right-hand column of the table on the slide.

EXPLAIN THAT there are different levels of sulphur (cystine/cysteine) in these different proteins:

- Low sulphur — associated with the crystalline parts of the fibre.
- High sulphur — associated with the cortex (non-crystalline regions) of the fibre.
- Ultra-high sulphur — associated with the exocuticle in the cuticle cells.



EXPLAIN THAT there are four types of crosslinks, or intermolecular bonds, that can occur between protein (polypeptide) chains and that these are outlined on the slide. Each of these crosslinks contributes to the stability of the fibre in various ways.

INFORM participants that the terms crosslink and intermolecular bonds are used interchangeably in this module.

EXPLAIN THAT the number of crosslinks depends on the composition of the local proteins in the crystalline regions and within the non-crystalline matrix regions.

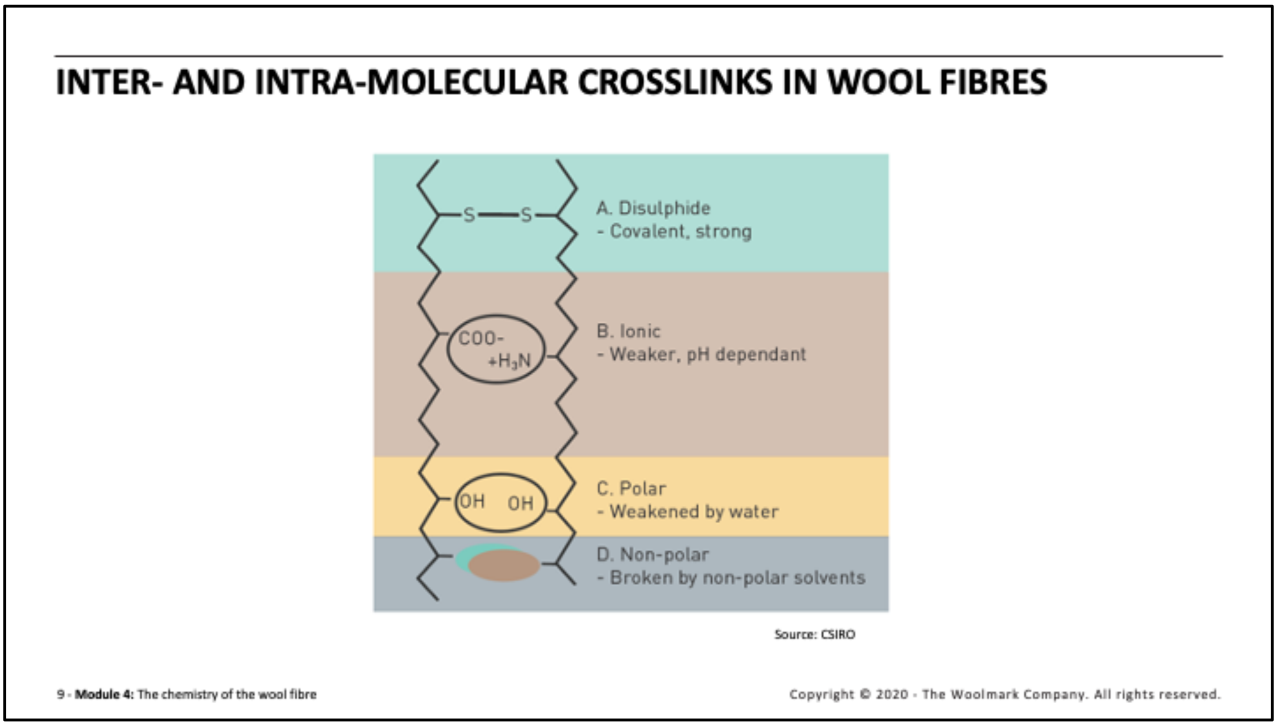
These crosslinks occur both within the molecule (intra-molecular) and between different protein chains (inter-molecular) and are as follows:

Disulphide crosslinks
As mentioned, disulphide crosslinks form between the sulphur side groups found in the amino acid cysteine. Where these disulphide crosslinks are formed, the resulting amino acid is called 'cystine'.

EXPLAIN THAT most of the sulphur in wool is in the form of cystine. These bonds are 'covalent' and are much stronger than the other crosslinks listed below. They are responsible for limiting the swelling or dissolution of the protein material in wool and contribute to the physical properties of wool fibres, particularly when the fibre is exposed to water.

BRIEFLY mention there are other covalent crosslinks between polymer chains. The number is normally quite small, but they include:

- **isopeptide crosslinks** — formed by condensation of acid side groups and amino side groups to form an amide (covalent bond). These crosslinks are difficult to detect and low in number.
- **lanthionine crosslinks** — are formed under alkaline conditions by beta-elimination of sulphur from a cystine crosslink, where cystine becomes a new amino acid, called 'lanthionine'. Lanthionine does not (and cannot) react like cystine in processing.
- **lysinoalanine** crosslinks — are formed under alkaline conditions by attack of the amino group on cystine.



EXPLAIN THAT there also are three types of 'non-covalent crosslinks' that form between the protein chains: ionic, polar and non-polar crosslinks, as outlined on the slide.

EXPLAIN THAT ionic crosslinks:

- form between side groups of amino acids that are positively charged and those of carboxylic acids, which are negatively charged
- are weaker than the covalent disulphide crosslinks
- are commonly known as 'salt bridges or salt links'.

The impact of these crosslinks depends on the pH of the fibre, as will be covered shortly.

EXPLAIN THAT polar crosslinks (interactions):

- occur between polar side groups found in serine, glutamine, histidine, asparagine, and amino and carboxyl groups
- can also involve the amide links in the polymeric chains
- are weakened by water.

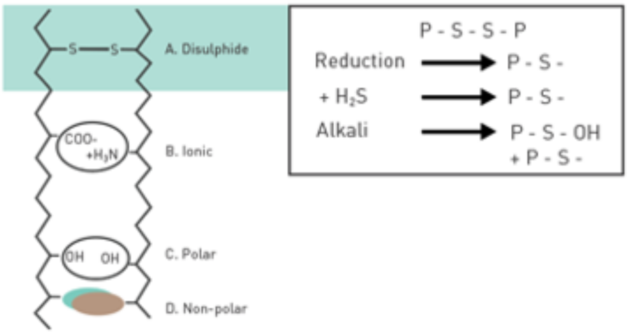
EXPLAIN THAT non-polar crosslinks (interactions)

- form between amino acids, which have non-polar (hydrophobic) side groups, such as phenylalanine, alanine and leucine
- are important only in the presence of water
- are broken by non-polar solvents
- are broken by high temperature.

EXPLAIN THAT you will now explore each type of crosslink in further detail, starting with disulphide crosslinks.

A. THE CHEMISTRY OF DISULPHIDE CROSSLINKS (CYSTINE)

- Strong covalent bonds, which limit relative movement of protein molecules when the fibre is deformed.
- Can be broken by:
  - reducing agent
  - thiols and H_2S
  - alkali.
- Reformed by oxidation:
  - in air
  - oxidising agents.



Source: CSIRO

10 - **Module 4:** The chemistry of the wool fibre

REMIND participants that the disulphide crosslinks that form in cystine are strong covalent bonds, which:

- limit the mobility of the protein molecules in the wool fibre
- can be intra- and inter-molecular (within and between protein chains)
- help to maintain the fibre shape and contribute to its resiliency when the fibre is deformed, especially in water.

EXPLAIN THAT the cystine disulphide crosslinks that occur between the protein chains within wool, can be broken by:

- reducing agents
- thiol (–SH-) compounds such as hydrogen sulphide (H_2S) and thioglycolic acid
- alkali.

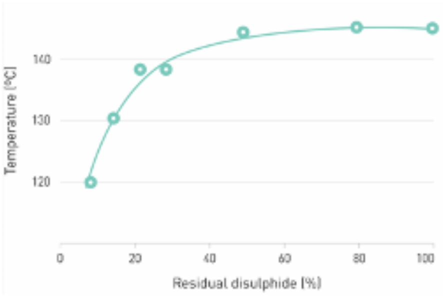
EXPLAIN THAT disulphide crosslinks can also be disrupted by the ionised thiol groups of cysteine.

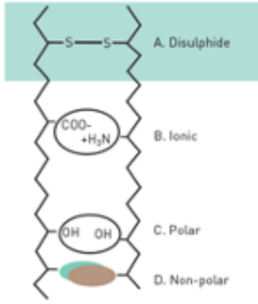
INDICATE THAT this breakage occurs via a nucleophilic attack. After the disulphide crosslinks are broken, they can be reformed by oxidation (by oxidising agents or in air).

DISULPHIDE CROSSLINKS — THE IMPACT ON THE FIBRE

Melting points of ‘wet wool’

- Untreated pH~4 150°C
- Disulphide reduced 120°C
- Crosslinked wool 156°C





GROUP	OLD NOMENCLATURE	NEW NOMENCLATURE
Keratin intermediate filament	Type I — low sulphur	K1.n
	Type II — low sulphur	K2.n
Proteins in cortex associated with keratin intermediate filament	High sulphur	KAP1.n KAP2.n KAP3.n

Information derived from CSIRO Australia

11 - **Module 4:** The chemistry of the wool fibre

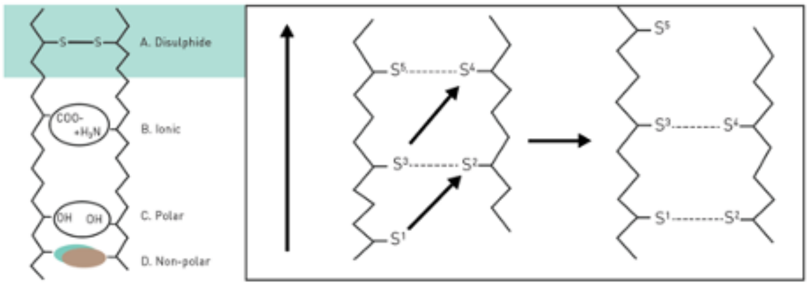
EXPLAIN THAT disulphide crosslinks (in cystine) also stabilise the crystalline regions of the fibre; the intermediate filaments (microfibrils). It is thought that this involves some of the matrix proteins associated with the intermediate filaments as shown in the table on the slide.

DIRECT participants to the figure on the slide as you explain that the removal of the disulphide crosslinks by reduction, slowly (and then more rapidly) lowers the melting point of wool when it is wet (i.e. the polar interactions are broken).

EXPLAIN THAT the addition of new chemical crosslinks to the fibre with, for example using formaldehyde, can reinforce the effect of the disulphide crosslinks, increasing the melting point of the fibre when wet.

DISULPHIDE INTERCHANGE

- Requires the presence of free thiol anions HS- , or free hydrogen sulphide (H_2S/ HS-)
- Allows permanent changes to the shape of the fibre.



EXPLAIN THAT in the presence of free thiol anions (—SH-) or free hydrogen sulphide (H_2S/HS-), cystine crosslinks can undergo a process in a deformed fibre called 'disulphide interchange'.

EXPLAIN THAT disulphide interchange results in the original strained disulphide crosslinks being broken and a new disulphide crosslink forming.

The free thiol anions (—S-) from cysteine or free hydrogen sulphide (H_2S/HS-) catalyse the interchange. If the thiol group is not ionised (e.g. at low pH), the interchange will not occur.

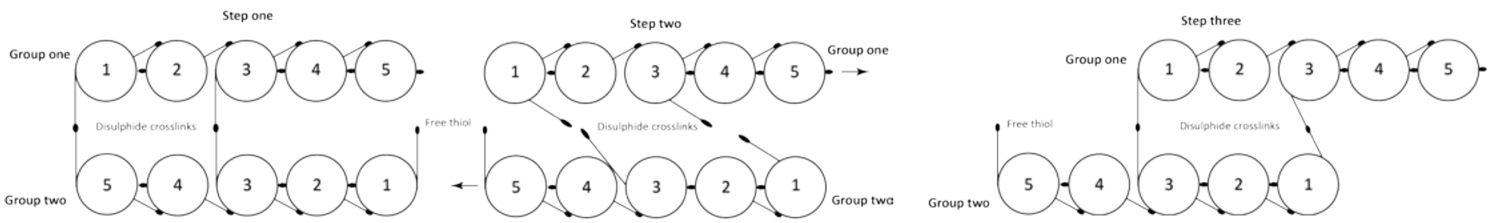
INDICATE THAT disulphide interchange is an extremely important process in wool processing. The broken disulphide crosslinks can be rearranged, allowing the fibre to take up a new permanent shape. This happens during the finishing process to give wool fabrics a stable flat and smooth finish.

INFORM students that as will be explained more fully in the next module — *Module 5: The setting of the wool fibre* — the setting of wool by disulphide interchange is required for the formation of 'permanent set'.

OFFER the related example of the manipulation of disulphide crosslinks in human hair as the basis for the 'permanent wave' or 'chemical straightening' in hairstyling. In contrast, hair that is 'blow-dried' is only cohesively or temporarily set.

DEMONSTRATION: DISULPHIDE CROSSLINKS

- ***Step one:*** *Arrange two groups of five students to form opposing rows. Students in each row stand side by side with one arm around the waist of student beside them. Ask students 1 and 3 from Group one and students 5 and 3 from Group two to reach across with their free hand and hold the hand of the opposing student to represent disulphide bonds. Ask student 1 in Group two to extend their hand to represent the free thiol. See Step one in diagram below.*
- ***Step two:*** *Ask student 1 from Group one to reach across and grab the hand of student 3 from Group two, forcing the student in their own row to let go. The newly freed student from Group one now grabs the hand of student one in group two (the free thiol form Step one).*
- ***Step three:*** *Ask the rows of students to move in relation to each other to represent the rearrangement of disulphide bonds and the free thiol.*



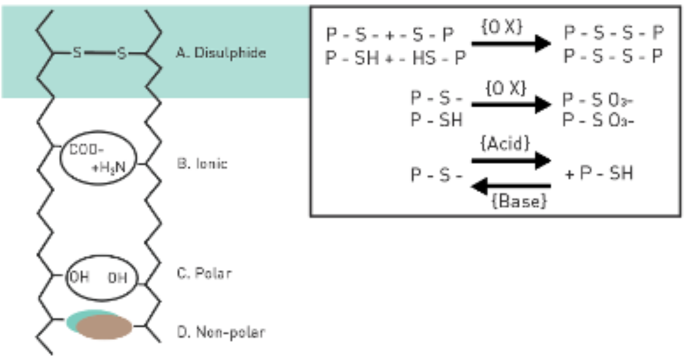
OXIDATION AND PROTONATION OF CYSTEINE

Oxidation of cysteine thiols:

- can reform the disulphide crosslinks
- can form other oxidised species, which cannot catalyse the disulphide interchange.

Protonation of cysteine:

- occurs at low pH
- protonated thiols do not catalyse the disulphide interchange.



EXPLAIN THAT cysteine thiols can react with other cysteine thiols via the process of oxidation to reform disulphide crosslinks. In other words, oxidation can help reform the covalent disulphide crosslinks. This restores (in part) the physical properties of the fibre.

EXPLAIN THAT stronger oxidation can also form other oxidised species, such as such as sulphonic acid (SO_{3-}).

NOTE THAT the oxidised sulphonic acid groups are unable to catalyse the disulphide interchange.

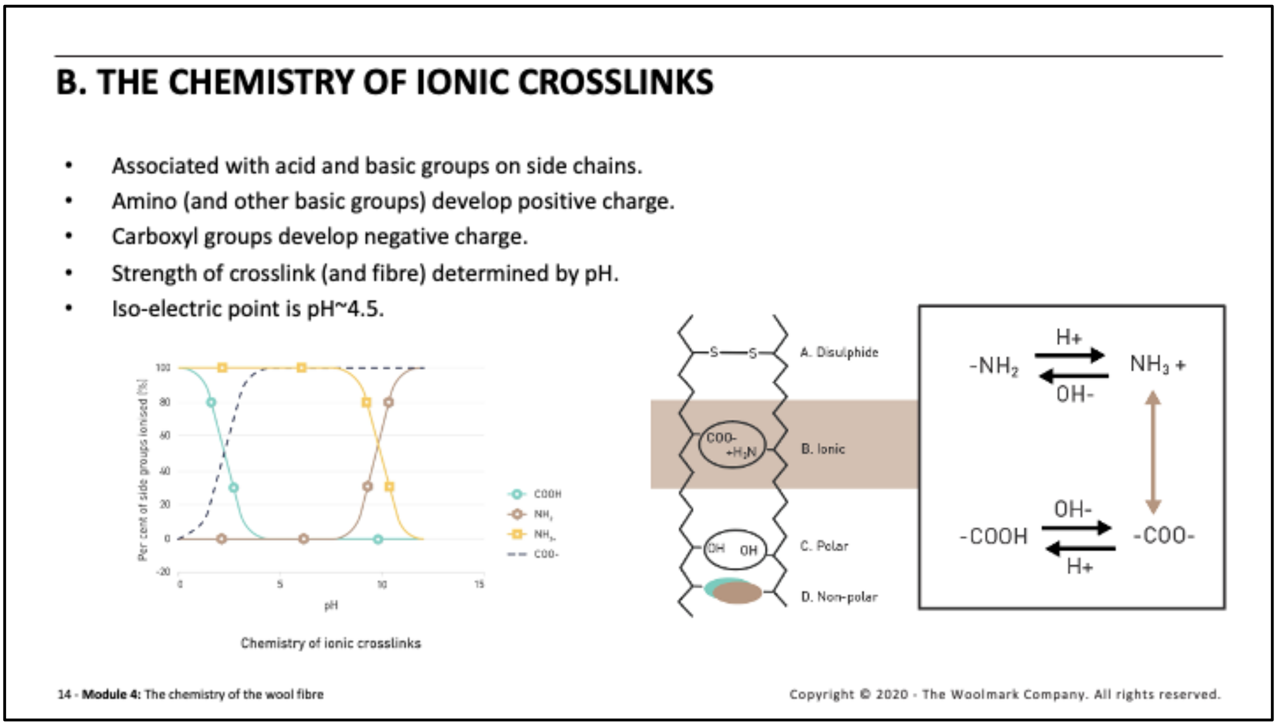
Likewise, free thiols that are protonated (SH), as a result of being in an acidic environment, are also unable to catalyse the disulphide interchange.

INFORM participants that the impact will be described in the next module — *Module 5: The setting of the wool fibre*.

EXPLAIN THAT you will now transition to discussing ionic crosslinks.

ASK participants if they have any questions about the chemistry of disulphide crosslinks before you move onto the chemistry of ionic crosslinks.

ADDRESS any questions in a timely manner.



EXPLAIN THAT ionic crosslinks form between positively and negatively charged side groups. These ionic crosslinks are sometimes called 'salt links'.

INDICATE THAT these salt links have a stabilising effect on the wool proteins (reducing damage and swelling) when they are wet.

PLAY THE animation as you explain that:

- At low pH (acidic conditions) the concentration of positively-charged (ammonium — NH_3+) groups is high and the number of negatively-charged (carboxylate — COO-) groups is low.
- At high pH (alkaline conditions) the concentration of positively-charged (ammonium — NH_3+) groups is low and the number of negatively-charged (carboxylate — COO-) groups is high.
- During the dyeing process, when the dyebath pH has a value around the iso-electric region of wool (i.e. the pH at which a molecule carries no net electrical charge — pH 4.5), the total concentration of charged amino and charged carboxyl groups is at a maximum and, the number of salt links is maximised.

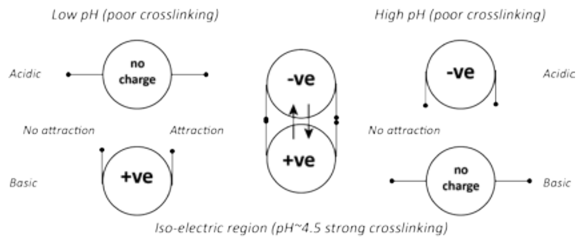
INDICATE THAT the strength of the ionic crosslink (and hence the strength of the wet wool fibre) is determined by the pH conditions of the surrounding environment.

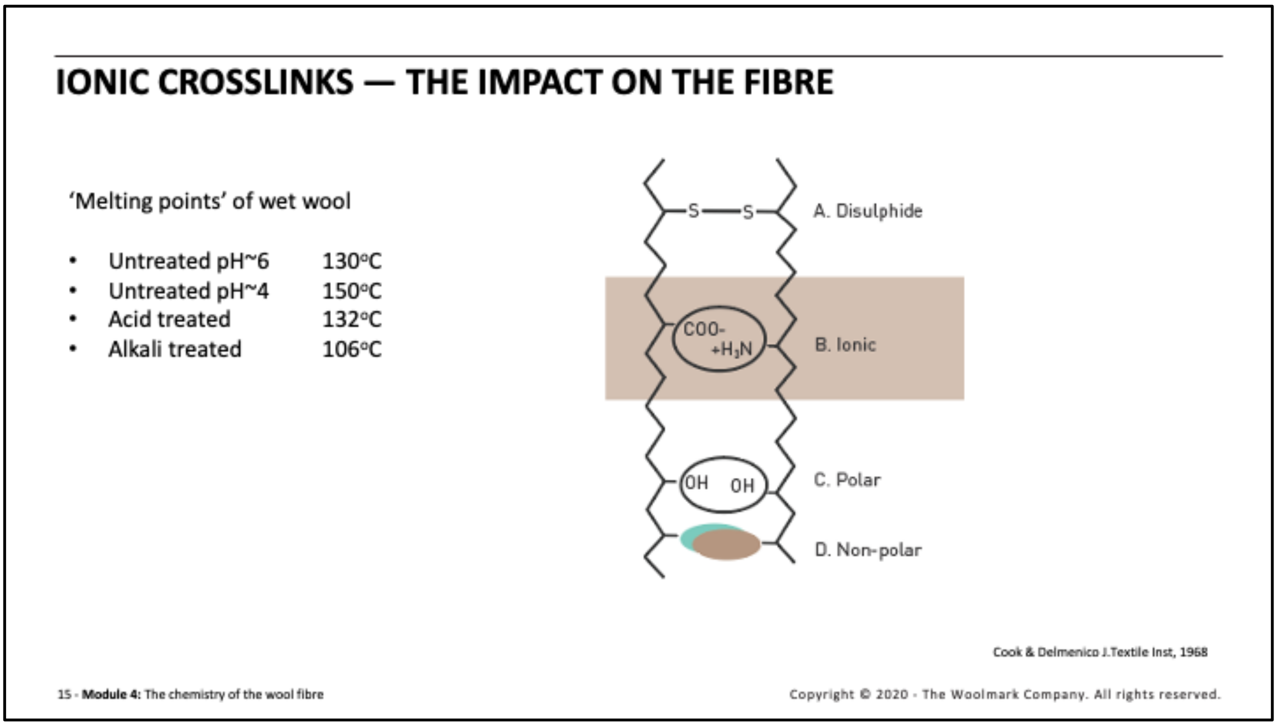
REFER to the left-hand figure on the slide and note that:

- at low pH only the amino groups are ionised and crosslinking is poor
- at high pH only the acidic groups are ionised and crosslinking is poor
- the wool fibre is most stable when the pH is ~4.5 (i.e. the iso-electric point) and the number of ionic crosslinks is maximised.

DEMONSTRATION — IONIC CROSSLINKS

- *Use three pairs of students to represent the effect of pH and charge on ionic crosslinks.*
- *One pair — one positive charge and one neutral charge at low pH (no attraction, as shown).*
- *One pair — one positive, one negative to represent a pH around the iso-electric region (students to 'attract' each other as shown in diagram below).*
- *One pair — one positive charge and one neutral charge at high pH (no attraction, as shown).*





EXPLAIN THAT like disulphide crosslinks, ionic crosslinks also contribute to the stability of the crystalline regions in wet wool fibres.

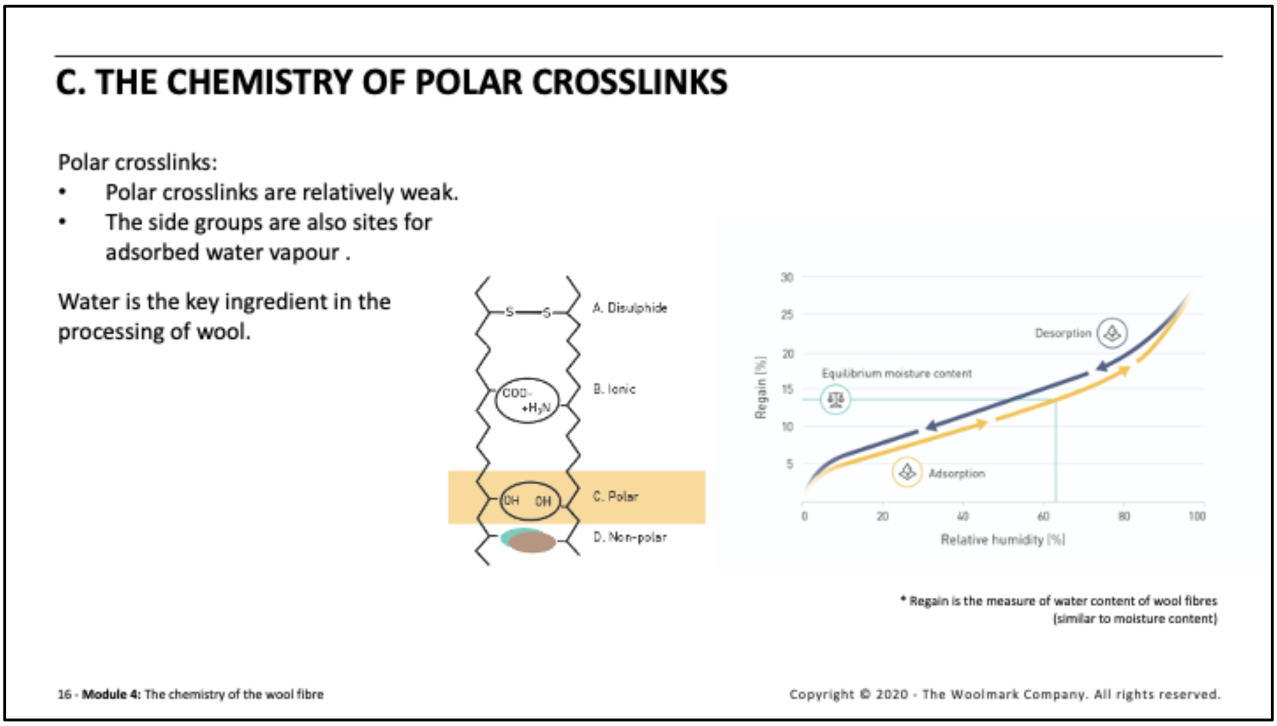
DIRECT participants to the effect of pH on the melting point of wool shown in the slide.

EXPAND ON the points on the slide by clarifying that:

- Near a pH of 4 the fibre melts at around 150°C in water.
- In acid solution (pH <4) the fibre melts at 132°C. The disruption of the ionic crosslinks, as well as the hydrolysis of the peptide links, contribute to this reduction in the melting point.
- In alkaline solution (pH >8) the fibre melts at 106°C. The disruption of the ionic crosslinks, as well as the hydrolysis of the disulphide crosslinks in alkaline solution, contribute to the reduction in the melting point.

ASK *participants if they have any questions about the chemistry of ionic crosslinks before you move onto the chemistry of polar crosslinks.*

ADDRESS *any questions in a timely manner.*



REINFORCE THAT polar groups form relatively weak intermolecular crosslinks called polar crosslinks (or bonds).

These crosslinks are numerous, forming between hydrophilic (water-loving) side chains as well as the amide (peptide) groups forming the polymer chains.

EXPLAIN THAT polar crosslinks are primarily responsible for the stability and properties of dry wool. A reduction in the number or effectiveness of these polar interactions:

- lowers the glass transition temperature (Tg) of the fibre
- lowers the rigidity of the fibre
- increases the extensibility of the fibre.

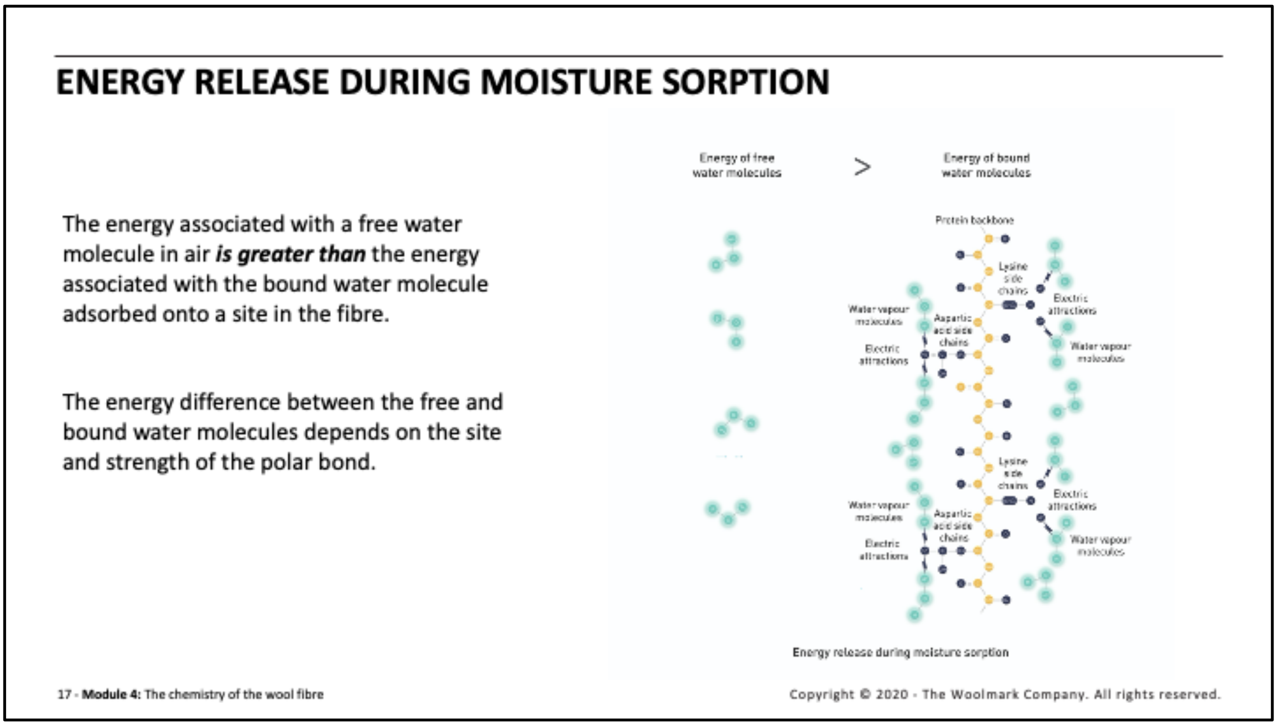
INDICATE THAT polar groups also form the sites for the adsorption of water by wool. Dry wool adsorbs water to reach equilibrium with the surrounding air.

EXPLAIN THAT this process is called ‘conditioning’ and it breaks the polar crosslinks within the fibre.

EXPLAIN THAT water ‘plasticises’ wool by breaking the polar interactions, which in turn:

- reduces the glass transition temperature
- makes the wool fibres less rigid
- causes the fibres to swell.

EMPHASISE THAT water is the most important ingredient in processing wool fabrics, because it ‘interacts’ with the protein molecules to change the properties of the fibre.



EXPLAIN THAT when wool adsorbs water, the water molecules release energy.

DIRECT participants to the illustration on the slide as you explain that the energy associated with a free water molecule in air is greater than the energy associated with the bound water molecule adsorbed onto a site in the fibre.

The combined energy states of the polar groups in dry wool and water in vapour form is greater than when the water is associated with the polar sites in the fibre.

EXPLAIN THAT the energy difference between the free and bound water molecules depends on the site and strength of the polar bond.

REMIND participants that the energy released when water is adsorbed onto the fibre makes the wool feel warmer, as discussed during the discussion about moisture adsorption in *Module 3 The physics of the wool fibre*.

REINFORCE with participants that this is an example of an 'exothermic' reaction.

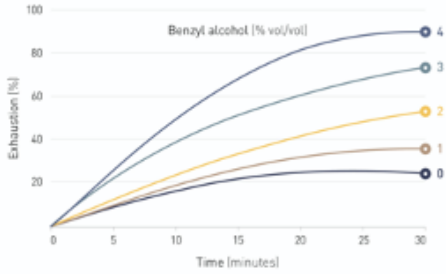
ASK *participants if they have any questions about the chemistry of polar crosslinks before you move onto the chemistry of non-polar crosslinks.*

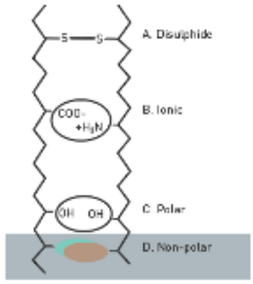
ADDRESS *any questions in a timely manner.*

D. THE CHEMISTRY OF NON-POLAR CROSSLINKS

Non-polar crosslinks are formed only when the fibre is in water and they:

- contribute to the wet strength of the fibre
- limit the swelling of the fibre in water
- are disrupted by water-soluble organic solvents (e.g. propyl alcohol and benzyl alcohol)
- are broken in water at temperatures >60°C.





REMIND participants that non-polar crosslinks are only formed when the fibre is in water and they:

- contribute to the wet strength of the fibre
- limit the swelling of the fibre.

EXPLAIN THAT non-polar crosslinks are disrupted by water-soluble organic solvents (such as propyl alcohol and benzyl alcohol). This results in greater fibre swelling and reactivity in water-solvent mixtures.

POINT OUT that non-polar crosslinks are broken in water temperatures >60°C.

REFER participants to the graph on the slide and explain that it shows the more rapid entry of dyes into wool fibres (i.e. rate of exhaustion) when an organic solvent (i.e. benzyl alcohol) is added to the dyebath with increasing concentration of the solvent.

REINFORCE THAT each coloured line on the graph represents an increasing concentration of solvent.

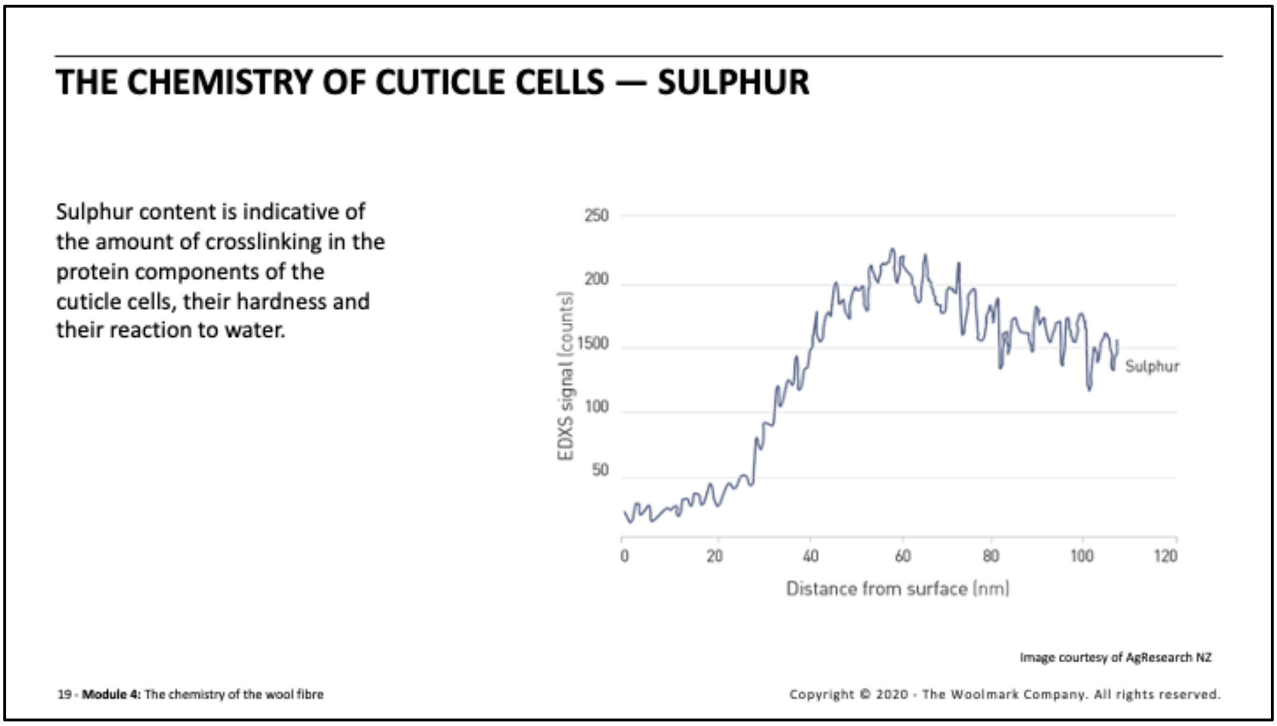
This is a result of the greater swelling of the fibre caused by the breaking of the hydrophobic interaction.

EXPLAIN THAT the use of organic solvents in commercial wool processing is limited.

ASK *participants why this might be the case and acknowledge responses (**ANSWER:** Cost and potential health issues.)*

ASK *participants if they have any questions about the chemistry of non-polar crosslinks before you move onto the chemistry of the cuticle cells.*

ADDRESS *any questions in a timely manner.*



EXPLAIN THAT sulphur content is indicative of the amount of crosslinking in the protein components of the cuticle cells, their hardness and their reaction to water.

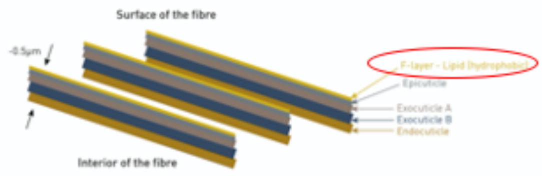
DIRECT participants to the graph on the slide and explain that it shows the sulphur content of wool fibre cuticle cells at various depths from the fibre surface.

EXPLAIN THAT on the surface of the cuticle cells (0–20nm) is the F-layer (proteolipid layer), where the sulphur content is low.

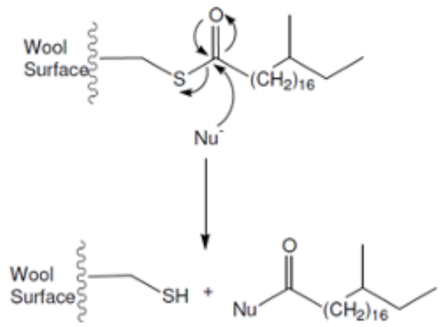
Deeper in the cuticle are the epicuticle and exocuticle, which contain more sulphur.

EXPLAIN THAT the deepest point in the cuticle is the endocuticle, which contains less sulphur than the epicuticle and exocuticle, but more sulphur than the F-layer.

CHEMISTRY OF CUTICLE CELLS — F LAYER



The surface layers of a wool fibre



F-layer

- Lipid material
- Held by weak thio-ester bonds $R_1 - S - CO - R_2$

20 - **Module 4:** The chemistry of the wool fibre

EXPLAIN THAT the chemistry of the various layers on the cuticle cells is quite complex.

EXPLAIN THAT the lipid layer (the major component of which is 18-MEA) on the surface of the wool fibre (F-layer) is held by weak thio-ester bonds ($R_1 - S - CO$ - R_2).

NOTE: A thio-ester is similar to an ester, except that it contains a sulphur atom in place of the oxygen.

REFER participants to the slide and indicate that the figure on the right-hand side shows the breaking of the thio-ester bond by a nucleophilic ion (e.g. hydroxide ion).

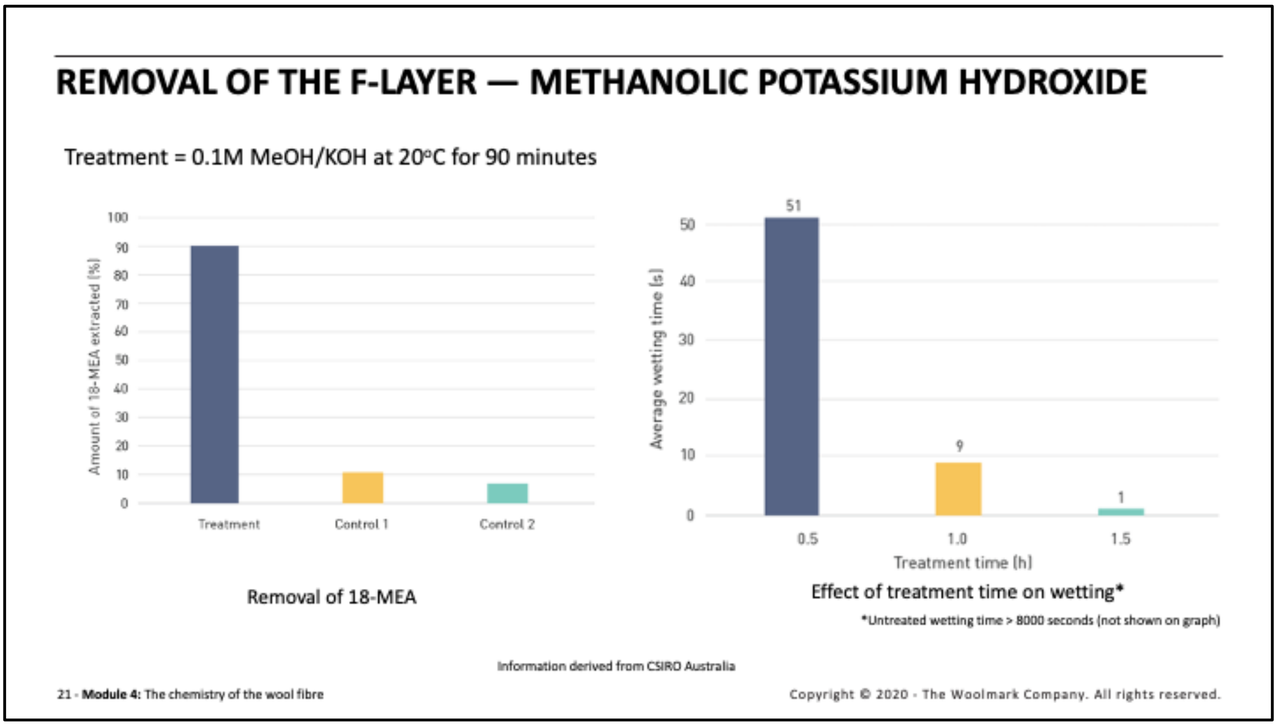
EXPLAIN THAT by breaking this bond the lipid layer can be removed, which is a critical step in developing ‘felt-resist’, ‘machine-washable’ wool products. The felt-resist treatment processes are covered in detail in *Module 6 The shrinkage of wool products.*

INDICATE THAT the lipid layer of the wool fibre can be removed by:

- chlorine (also degrades the underlying proteins)
- some oxidizing agents (also degrade proteins)
- some enzymes
- some nucleophilic agents in solvent water mixtures, including:
    - methanolic KOH (potassium hydroxide dissolved in methanol)
    - potassium t-butoxide
    - hydroxylamine
    - alkali dissolved in n-propanol
- plasma (partially).

NOTE THAT some surfactants catalyse the removal of the lipid by oxidising agents and alkali.

INDICATE you will now explore removing the F-layer (lipid layer) uisng methanolic KOH and plasma.



EXPLAIN THAT the effect of methanolic potassium hydroxide (MeOH/KOH) on the lipid layer (F-layer — 18-MEA) of the wool fibre is shown in the figures on the slide.

Figure 1 (left) indicates that treating the wool fibre with 0.1M MeOH/KOH at 20ºC for 90 minutes removes large amounts of fatty acids (lipid material) from the fibres.

The control treatments with methanol only (Control 1) or potassium hydroxide in water only (Control 2) remove much less lipid material.

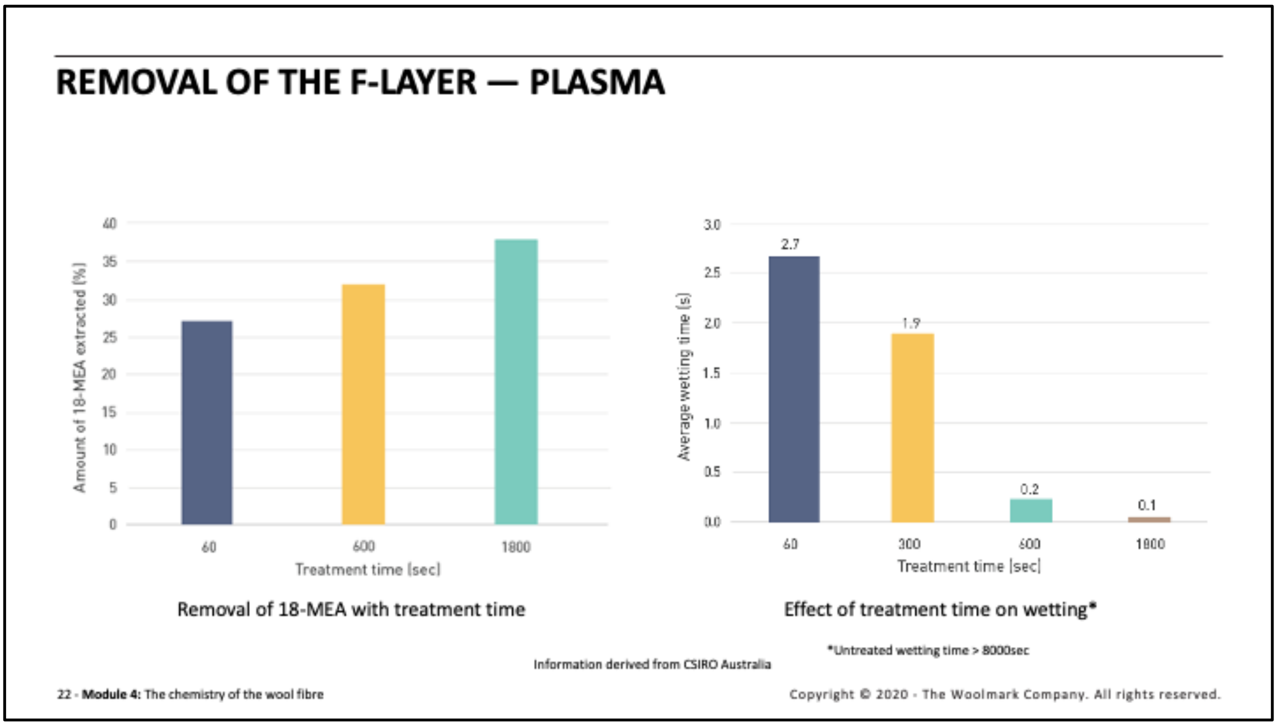
EXPLAIN THAT it is proposed that the alcohol component of the treatment disrupts the hydrophobic (water resistant) nature of the fatty acid chains on the lipid material, allowing access to the thioester group, which is hydrolysed by the alkali.

EXPLAIN THAT Figure 2 (right) illustrates that removing the hydrophobic F-layer reduces the wetting time for wool fibres from in excess of 8000 seconds to just a few seconds.

NOTE THAT the untreated wetting time is not shown on the graph.

ASK participants to note that at 20ºC the effectiveness of the treatment increases with time to 90 minutes in Figure 2.

REMIND PARTICIPANTS of the demonstration carried out on delipidised and untreated wool fabric in Module 2.



REINFORCE that plasma can also be used to remove the hydrophobic F-layer from the wool fibre.

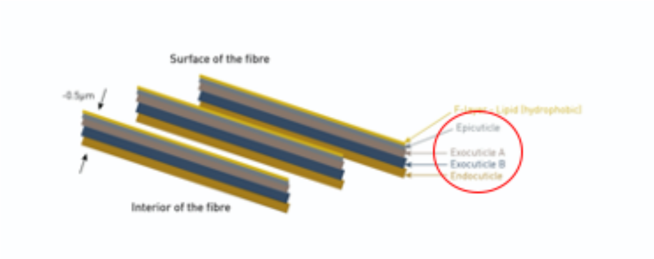
REFER participants to the slide as you explain that as indicated by Figure 1 on the left of the slide, the amount of fatty acid (lipid material — 18-MEA) removed from the fibre increases with the time of plasma treatment

This correlates with the reduction in wetting time for the wool fibres as the lipid layer is removed, shown by Figure 2 on the right-hand side of the slide.

***ASK** participants if they have any questions about the chemistry of the cuticle cells before you move onto the chemistry of the cuticle cells beneath the F-layer.*

***ADDRESS** any questions in a timely manner.*

THE CHEMISTRY OF CUTICLE CELLS — BENEATH THE SURFACE



The epicuticle:

- resistant membrane surrounding all cells within the fibre
- raised sacs in Allworden reaction (filled with solubilised protein).

The exocuticle

- 60% of the cuticle cell
- hard, highly crosslinked material
- resists swelling in water
- has two sections:
  - A layer: heavily crosslinked (~35% half-cystine)
  - B-layer: (~15% half cystine).

The endocuticle:

- less heavily crosslinked
- swells more in water
- mechanically weaker.

23 - **Module 4:** The chemistry of the wool fibre

EXPLAIN THAT the components of the cuticle cells beneath the F-layer also have unique chemistry.

REVIEW the following points with the group:

The epicuticle

- The epicuticle is also called the 'resistant membrane' and surrounds all cells within the fibre.
- When a wool fibre is placed in chlorine water, bubbles or sacs develop on the surface (i.e. the Allworden reaction).
- These raised sacs are the epicuticle or resistant membrane.
- The sacs are filled with liquid containing solubilised protein from the exocuticle layer
- The epicuticle will slowly dissolve in chlorine water.

The exocuticle

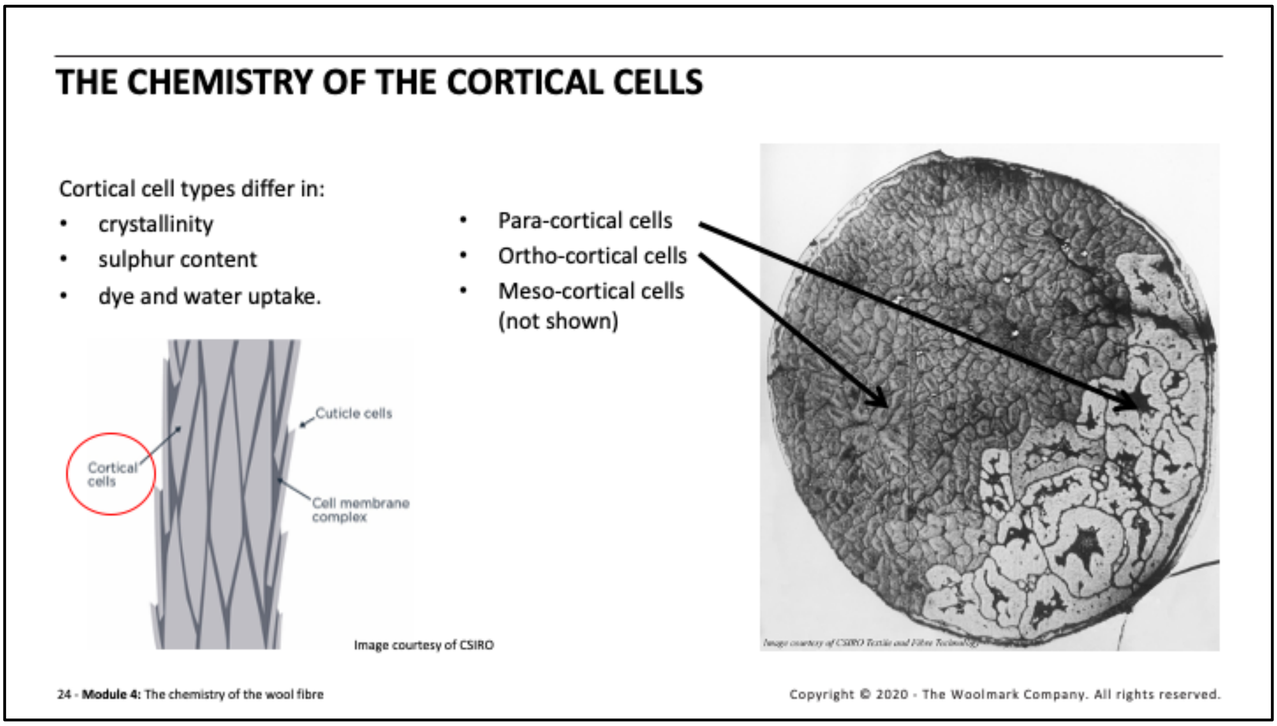
- The exocuticle is a hard highly crosslinked material, which resists swelling in water and forms about 60% of the cuticle cell.
- The exocuticle has two layers:
  - the A layer (~30–50% of the total exocuticle material) is heavily crosslinked (~35% half-cystine)
  - the B-layer (~15% half cystine)
- Both layers dissolve rapidly in chlorine solution as the disulphide crosslinks oxidise and break.

The endocuticle

- The endocuticle is less heavily crosslinked (~3% half-cystine) and swells more in water than the exocuticle.
- It is mechanically weaker than other parts of the cuticle.
- The endocuticle is primarily responsible for the swelling of the cuticle cells in water and the lifting of the scale edges.

ASK *participants if they have any questions about the chemistry of the cuticle beneath the F-layer before you move onto the chemistry of the cortical cells.*

ADDRESS *any questions in a timely manner.*



ASK participants if they can recall the name given to the schematic on the left-hand side of slide illustrating the structure of the wool fibre and acknowledge their responses. (**ANSWER:** Brick and mortar [and tile] model.)

EXPLAIN THAT the three types of cortical cells in wool fibres (orth-cortical, para-cortical and meso-cortical) differ in:

- crystallinity
- sulphur content
- rate of dye and water uptake.

BRIEFLY outline the following points for each cortical cell type:

Ortho-cortical cells:

- are more crystalline
- contain less sulphur (i.e. less cystine)
- take up dye more slowly
- are more reactive (possibly associated with differences in type of matrix material).

Para-cortical cells:

- are less crystalline
- contain more sulphur (i.e. more cystine)
- take up dye more quickly (i.e. higher rates of water uptake).

Meso-cortical cells:

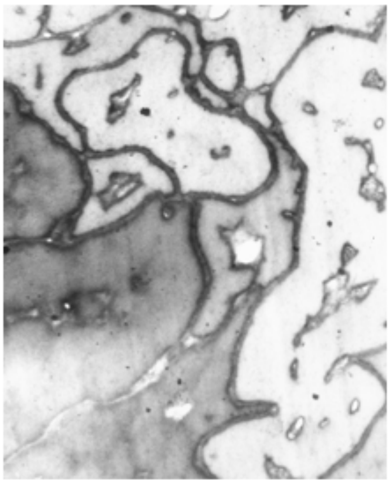
- are smaller in number than the other cell types (~4% of fibre), hence have little impact on dye and water uptake.

EXPLAIN THAT the difference in dye uptake by the cortical cells rarely has any impact on the external appearance of dyed wool, but can be seen on microscopic studies of the fibre cross section shown on the slide.

ASK *participants if they have any questions about the chemistry of the cuticle beneath the F-layer before you move onto the chemistry of the cortical cells.*

ADDRESS *any questions in a timely manner.*

THE CHEMISTRY OF THE CELL MEMBRANE COMPLEX (CMC)



Cell membrane complex

- The CMC acts as a pathway for dyes.
- Mechanical finishing does not affect the CMC.
- Chemical finishing can affect the CMC.

Image courtesy of CSIRO Textile and Fibre Technology

25 - **Module 4:** The chemistry of the wool fibre

EXPLAIN THAT the chemistry of the cell membrane complex (CMC) is quite complex since it contains keratinised and non-keratinised proteins as well as lipid material.

INDICATE THAT the impact of the chemistry of the CMC in conventional wool fabric finishing is normally limited to piece dyeing operations.

- The CMC acts as the primary pathway for the entry of dyes into the interior of the fibre, especially at the start of the dyeing.
- Damage to the CMC may result in changes in the rate of dye uptake.

EXPLAIN THAT mechanical processing operations (e.g. scouring and milling) don't normally affect the CMC directly.

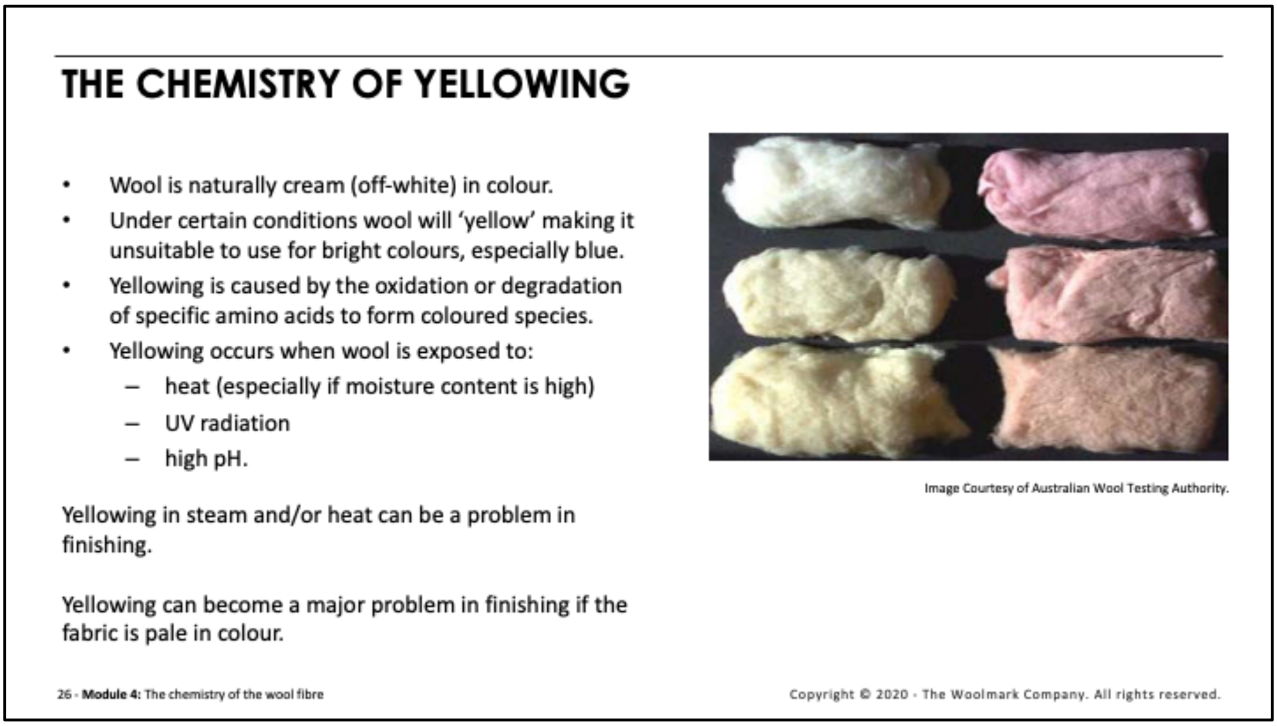
EXPLAIN THAT chemical processes (e.g. felt-resist treatment) can modify the CMC. This may impair the ability of the fibre to resist abrasion.

EXPLAIN THAT some polar solvents (e.g. methanol-butanol and formic acid) also modify the CMC.

- The mechanism may involve the removal of unbound lipids, which weaken the interface between cells.
- These modifications can improve abrasion resistance.

ASK *participants if they have any questions about the chemistry of the CMC before you move onto the chemistry underpinning the yellowing of wool.*

ADDRESS *any questions in a timely manner.*



***HAND OUT** samples of 'yellow' and 'normal' wool for participants to observe as you explain the concept of yellowing.*

EXPLAIN THAT wool is naturally cream (off-white) in colour due to the presence of coloured compounds within the fibre. Under certain conditions wool will 'yellow' making it unsuitable to use for bright colours, especially blue.

INDICATE THAT the image on the slide shows the impact of the base colour of the wool sample on the resultant shade of the dyed product.

EXPLAIN THAT yellowing of wool is caused by the oxidation or thermal degradation of specific amino acids — tryptophan, tyrosine and phenylalanine. These amino-acids decompose or react with oxygen to form coloured compounds, which make the wool look 'yellow'.

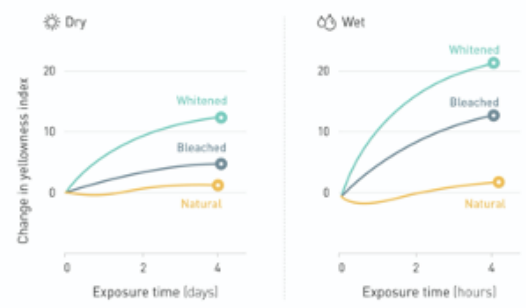
INDICATE THAT yellowing can occur when wool is:

- heated, especially if moisture content is high (e.g. wool will yellow rapidly in steam, which occurs during fabric finishing).
- exposed to UV radiation (e.g. sunlight). Tryptophan, tyrosine and phenylalanine all absorb UV radiation and degrade to form coloured products.
- exposed to highly alkaline conditions (e.g. pH>11). Wool with a high pH yellows faster in UV light or at high temperatures.

EXPLAIN THAT yellowing, or colour change of wool, is a major problem when finishing wool fabric, especially if the shade of the fabric is pale.

THE MECHANISMS IN WOOL PHOTO-YELLOWING

- Radicals are generated when UV radiation is adsorbed by specific amino acids (e.g. tryptophan and tyrosine).
- The radicals react with oxygen to form new radical species.
- Yellowing occurs by radical attack on susceptible amino acids.
- These amino acids react to form coloured species.
- Wool yellows more rapidly when wet than when dry.
- Inclusion of an optical brightening agent facilitates yellowing.



Mechanisms of photo-yellowing in wool

Source: CSIRO

http://archive.sheepcrc.org.au/files/pages/articles/sheep-crc-wool-conference-2012/KEITH_MILLINGTON___THE_EVERWHITE_WOOL_STORY.pdf

27 - **Module 4:** The chemistry of the wool fibre

REINFORCE THAT photo-yellowing of wool is caused by the oxidation of specific amino acids (e.g. tryptophan, tyrosine, and phenylalanine).

EXPLAIN THAT radicals are generated when sunlight is adsorbed by the UV-adsorbing amino acids in the fibre (e.g. tryptophan and tyrosine).

The radicals react with oxygen to form new radical species, which have considerable oxidative power.

Yellowing occurs when radical oxygen species attack the susceptible amino acids, which form coloured species.

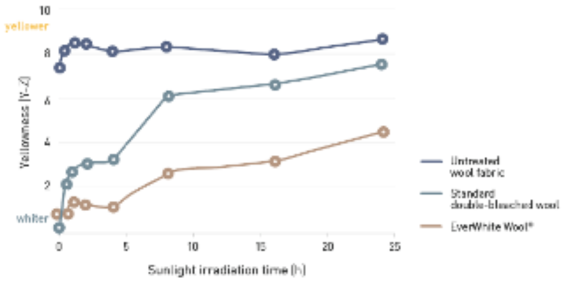
DIRECT participants attention to the images on the slide as you explain that wool 'photo-yellows' more rapidly when wet than when dry due to the formation of hydroxy radicals

INDICATE THAT the inclusion of an optical brightening agent on the fibre also increases the formation of free radicals and facilitates yellowing.

EXPLAIN THAT yellowing or colour change is a major problem in the maintenance of washable wool fabric, which must be dried in the shade, to avoid exposure to UV, especially if the fabric is pale in colour.

REDUCING PHOTO-YELLOWING

- Untreated and bleached wool is susceptible to photo-yellowing when exposed to sunlight.
- Treating wool with a water-soluble UV-absorber in combination with reductive bleaching can reduce the impact of sunlight on susceptible amino acids in the wool fibre, producing a photo-stable product.
- The EverWhite Wool© process was developed in Australia.



Inhibiting wool yellowing

http://archive.sheepcrc.org.au/files/pages/articles/sheep-crc-wool-conference-2012/KEITH_MILLINGTON___THE_EVERWHITE_WOOL_STORY.pdf

28 - **Module 4:** The chemistry of the wool fibre

EXPLAIN THAT treating wool during after bleaching with a reagent that absorbs the ultraviolet light can reduce the radical attack on susceptible amino-acids and the resulting yellowing of the wool fibre, as shown on the slide.

NOTE THAT one such commercial UV-absorbing reagent is Cibafast W, which was developed in Australia to protect wool upholstery from the damage caused by prolonged exposure to the Sun.

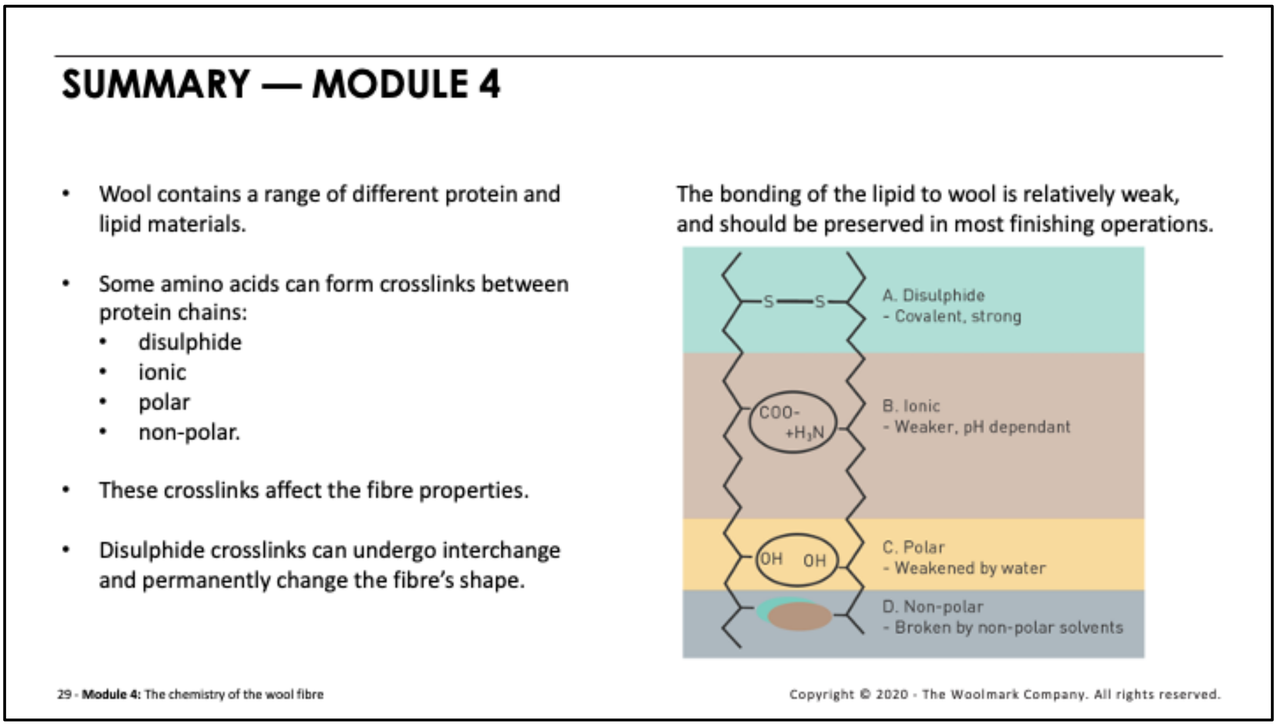
INDICATE THAT developed in Australia, the EverWhite Wool© process, significantly slows the natural yellowing process caused when bleached wool fabrics are exposed to sunlight.

EXPLAIN THAT the EverWhite Wool process allows more photo-stable wool products to be created in white and pastel shades. The process involves the use of a UV-absorbing reagent, UVFast W, a product similar to Cibafast W, which was already known to reduce the rate of both photo-yellowing and photo-tendering (the loss of strength) of wool on extended exposure to sunlight. When applied to wool using the traditional method this UV absorber discoloured the fabric, effectively preventing its use for white wool products.

EXPLAIN THAT the the EverWhite Wool process involves applying UVFast W in combination with the reductive bleaching component of a two-stage bleaching process. It results in a wool fabric that remains whiter and brighter than unbleached wool even when the unbleached wool is treated with the UV absorber. The UVFast W cannot be used in combination with fluorescent whitening agents – the UV wavelengths present in sunlight that are necessary to 'excite' the whitening agents are absorbed by UVFast W.

NOTE THAT Australian researchers proved the performance of the EverWhite Wool process by testing three sets of fabrics for yellowing under artificial sunlight — untreated wool fabric, double-bleached wool fabric and wool fabric double bleached and treated with UVFast W. As shown in the graph, the whiteness achieved by the EverWhite Wool treatment is comparable to the brightness of bleached wool, but undergoes very little change in yellowness during the initial and early periods of exposure.

ENCOURAGE PARTICIPANTS to go to the following link for more information: https://web.archive.org.au/awa/20190403221707mp_/https:/www.sheepcrc.org.au/files/pages/information/news/everwhite-wool-keeps-wool-whiter-for-longer-23-09-2013/Everwhite_Wool_MR_FINAL_170923.pdf



SUMMARISE this module by briefly reviewing the following points:

Wool contains a range of different protein and lipid materials.

Some amino acids can form crosslinks:

- disulphide
- ionic
- polar
- non-polar.

These crosslinks affect the fibre properties.

Disulphide crosslinks can undergo interchange and permanently change the fibre's shape.

The bonding of the lipid to wool is relatively weak, and should be preserved in most finishing operations.

SUMMARY — MODULE 4

- Yellowing of wool is associated with the oxidation or degradation of specific amino acids.
- In fabric finishing, yellowing occurs rapidly in:
  - steam or heat at high humidity
  - highly alkaline conditions (high pH).
- Yellowing in steam and/or heat can be a problem during the finishing process.
- Photo yellowing on extended exposure to sunlight occurs more rapidly:
  - in wet wool
  - in chemically bleached wool
  - In optically whitened.
- The EverWhite Wool process can reduce photo-yellowing in bleached wool products.

30 - **Module 4:** The chemistry of the wool fibre

REINFORCE that yellowing of wool is associated with the oxidation or degradation of specific amino acids.

EMPHASISE that during fabric finishing, yellowing occurs rapidly in:

- steam or heat at high humidity
- highly alkaline conditions (high pH).

REMIND participants that yellowing in steam and/or heat can be a problem during the finishing process.

REINFORCE that photo-yellowing on extended exposure to sunlight occurs more rapidly:

- in wet wool
- in chemically bleached wool
- in optically whitened.

FINISH by reminding participants that the EverWhite Wool process can reduce photo-yellowing in bleached wool products.

ASK *participants if they have any questions about the content covered in this module.*

ALLOW *time for questions and discussion before proceeding to the final slide and closing the lecture.*

INFORM participants of the time and location for the next lecture — *Module 5 The setting of the wool fibre* — and ensure they read through the relevant notes in their Participant Guides before attending the lecture.

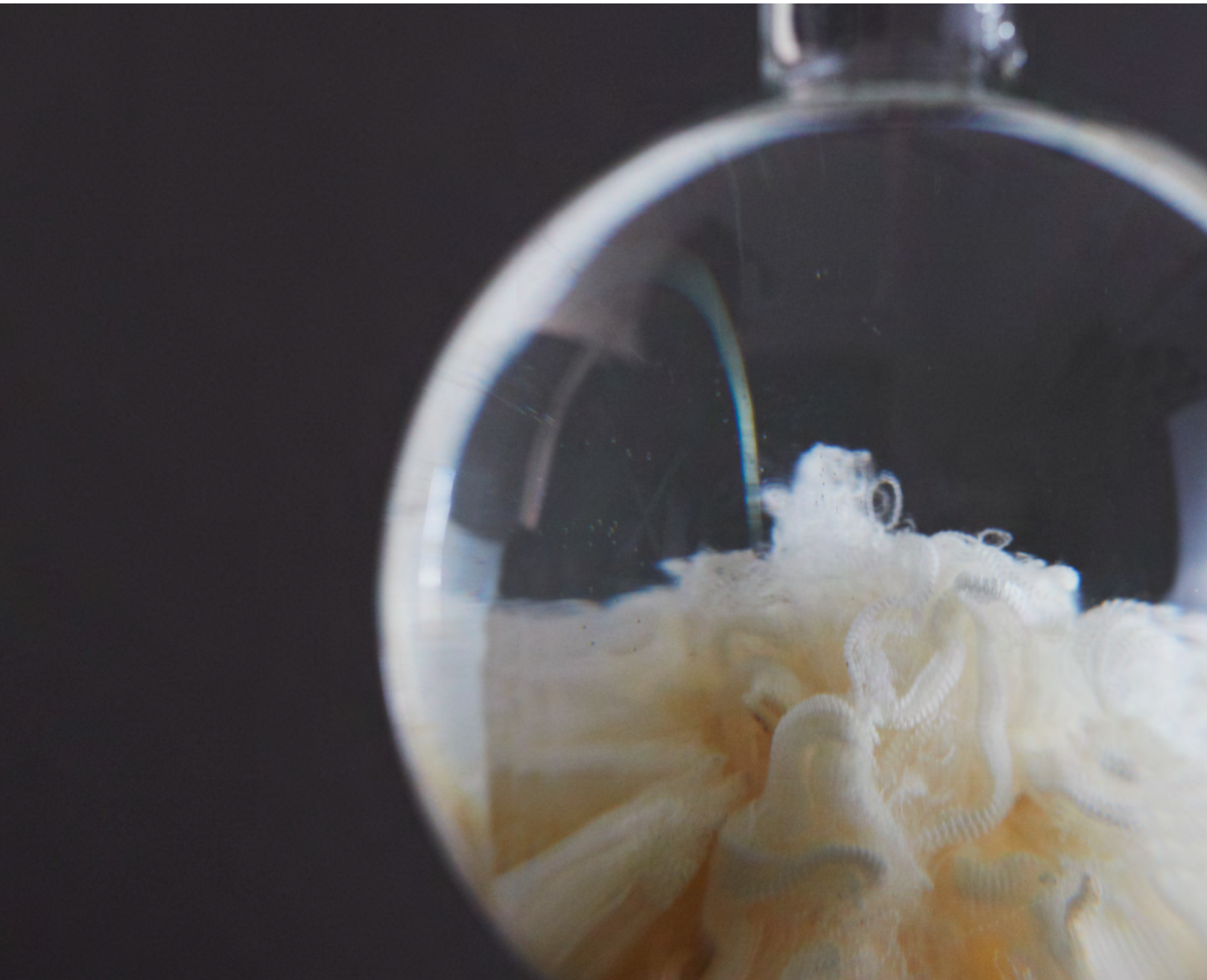
ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in today's lecture.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

BEFORE participants leave ensure you have collected all fibre samples distributed during the lecture.

MODULE 5

THE SETTING OF THE WOOL FIBRE



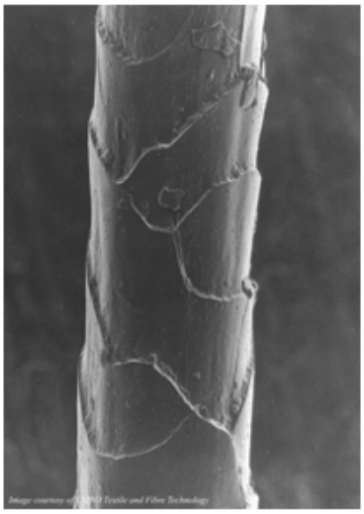
RESOURCES — MODULE 5: THE SETTING OF THE WOOL FIBRE

Contained in the *Wool fibre science* Demonstration kit you will find the following resources for use as you deliver **Module 5: The setting of the wool fibre**:

- wool fabric
- conditioned wool fabric
- dry wool fabric
- wool fabric set in pressure decatiser
- wool fabric pressed with an iron.

WELCOME participants to Module 5 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The setting of the wool fibre*.

SETTING OF WOOL FIBRES



- The concept of set and setting
- When setting occurs
- Different types of set:
  - cohesive
  - temporary
  - permanent
- Mechanics of setting
- Setting processes

2 - **Module 5:** The setting of the wool fibre

EXPLAIN THAT as listed on the slide, this module will explore the process of 'setting' and will outline:

- the concept of set and setting
- when setting occurs during manufacture and wear
- the three key types of setting (i.e. cohesive, temporary and permanent setting) and the differences between each of them
- the mechanisms of setting in terms of the physics and chemistry of wool
- some of the processes used to set wool.

INFORM participants that by the end of this module they will be able to:

- describe three types of wool setting (i.e. cohesive, temporary and permanent) and the conditions required for each to be successfully achieved
- describe the mechanism of each type of wool set, in terms of glass transition behaviour and fibre crosslinking
- describe methods for increasing the rate of setting
- describe methods for reducing the rate of setting.

RESOURCES REQUIRED FOR THIS MODULE

- *wool fabric*
- *conditioned wool fabric*
- *dry wool fabric*
- *wool fabric set in pressure decatiser*
- *wool fabric pressed with an iron.*

DEMONSTRATION — COHESIVE SET

- *Sample of unfolded conditioned wool fabric on a sealed plastic bag (Sample B)*
- *Sample of unfolded dry wool fabric on a sealed plastic bag (Sample C)*
- *whiteboard markers*

ASK *for three participant volunteers to help with the demonstration.*

EXPLAIN *that you have three samples of folded wool fabric (wet, conditioned and dry), one in each bag. Take each unfolded sample from the bag and show it to the group before folding it and placing it in a sealable plastic bag with the appropriate label.*

ASK *each volunteer to take a sample, in the bag and place it on their seat and take their seat, with the fabric sample directly under their weight.*

EXPLAIN *that each sample will remain underneath the seated participant for the during of the lecture.*

ASK *participants to predict which of the folded samples will form the sharpest crease by the end of the lecture (Sample A, B or C).*

RECORD *participant predictions as tallies under A, B or C on the whiteboard or flipchart.*

EXPLAIN that during this lecture you will be exploring the processes used to form and stabilise folds (creases or 'set') in wool fabrics — setting.

THE SETTING OF WOOL

Setting operations:

- require stress relaxation of the deformed fibres
- require rearrangement of protein molecules within the fibre
- are critical in conventional finishing.
- are conducted on both wet and dry wool.

Wool fabrics are set:

- in loom state
- after wet finishing
- in dry finishing
- in garment manufacture
- in garment aftercare.

3 - **Module 5:** The setting of the wool fibre

EXPLAIN THAT setting is a process that changes the shape of a wool product by 'deforming' it under conditions where it will not return to its original shape (i.e. 'relax' as discussed in *Module 3 The physics of the wool fibre*).

DEMONSTRATION — DEFORMATION AND SET

Resources required:

- *plasticine*
- *rubber ball (e.g. tennis ball).*

***PLUNGE** your thumb into the plasticine and remove, noting the permanent depression (i.e. deformation) left by your thumb.*

Press your thumb into the rubber ball and remove, noting the immediate return to the original from.

***REINFORCE** that the tennis ball cannot be permanently 'set' (i.e. it immediately recovers to its original shape after the pressure is removed), while the plasticine remains in the new, 'deformed' shape.*

EXPLAIN THAT both setting and the release of set (i.e. relaxation) require movement of the protein molecules within the fibre. This, in turn, requires rearrangement of some of the crosslinks between the protein molecules.

EXPLAIN THAT setting operations are among the most critical in the conventional finishing of wool fabric and garments.

These operations can be carried out on either wet or dry wool and normally on both.

EXPLAIN THAT wool fabrics are set in one or more of the following processing stages:

- in loom state (i.e. before wet finishing)
- after wet finishing
- in dry finishing
- in garment manufacture
- in garment aftercare.

THE TYPES OF SET IN WOOL

Three types of set are used in wool processing:

1. Cohesive set: released when wool is wet out or heated in steam.
2. Temporary set: stable in cold water, but lost in water at 70°C for 30 minutes.
3. Permanent set: stable to release in water at 70°C for 30 minutes.

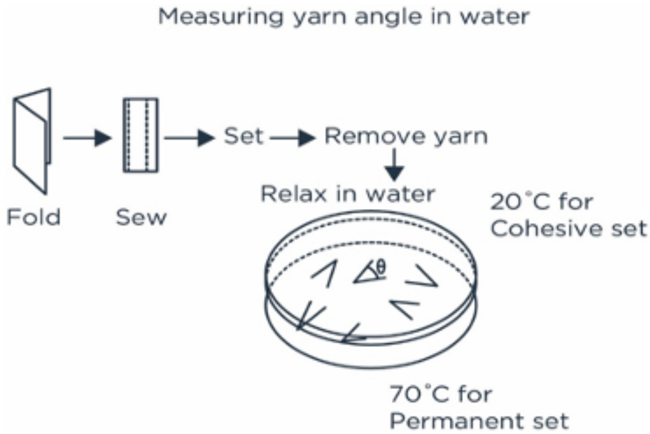


Image courtesy of CSIRO Australia

4 - Module 5: The setting of the wool fibre

EXPLAIN THAT there are three different types of set normally recognised in wool fibres:

- Cohesive set is released when wool is wet out at 20ºC (or heated in steam).
- Temporary set is stable in cold water but lost in water at 70°C for 30 minutes.
- Permanent set is stable to release in water at 70°C for 30 minutes.
    - In some of the early literature, permanent set was defined as the set stable to boiling water for 1hr.
    - Some studies on the setting of wool fibres may refer to these conditions.

NOTE that some text books do not distinguish between cohesive and temporary set. The difference is thought to be merely a difference in the rate of release of set in water at 20ºC and 70ºC.

EXPLAIN THAT during wool processing:

- some operations require cohesive or temporary set (pressing after dry cleaning)
- some operations require permanent set (permanent pleats in skirts)
- in some operations, finishers try to avoid permanent set (in fabric dyeing)
- some operations require all forms of set (i.e. pressure decatising).

HIGHLIGHT THAT being able to distinguish between the various forms of set and the type of set imparted in the various operations is critical to correct finishing and to the evaluation of setting techniques in fabric.

EXPLAIN THAT the test to distinguish between cohesive, temporary and permanent set involves measuring yarn angle in water, and is illustrated on the slide.

- A fold is placed in the yarn or fabric
- The wool is then 'set' under the required conditions.
- A snippet of yarn from the fold is extracted from the fabric.
- The snippet of yarn is placed in water at 20ºC for 30 minutes.
- A second snippet also from the fold is placed in water at 70ºC for 30 minutes.
- The angle formed by the yarn is measured.

Set % = 100 * (180-angle)/180

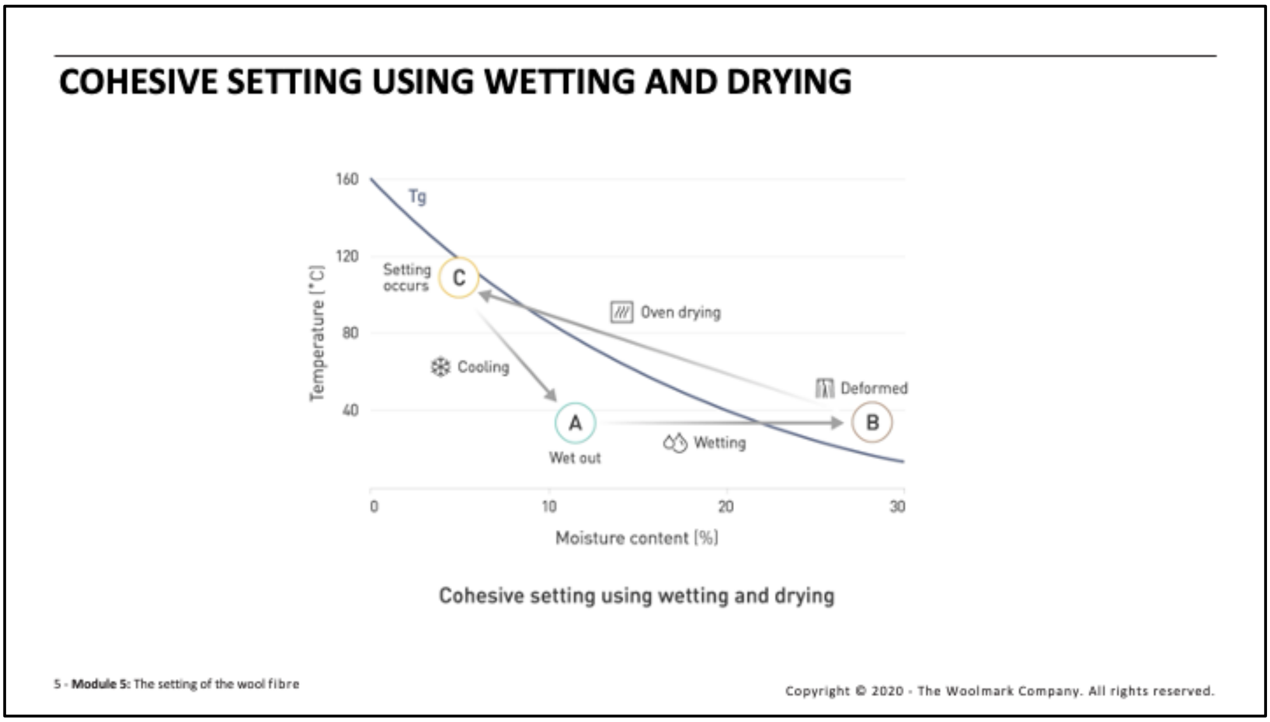
DEMONSTRATION — TYPES OF SET

Resources required

- *Overhead projector and screen*
- *Glass petri dish*
- *Water (enough to half fill petri dish)*
- *Scissors*
- *Permanently set (decatised) wool fabric*
- *Ironed wool fabric*

Cut snippets of each fibre sample (ensuring you retain the 'fold' in the snippet sample) and place each sample in the petri dish on the glass screen of the overhead projector so participants can observe the results on the screen.

COMPARE THE *results with the image on the slide and confirm the concepts of permanent and cohesive set.*



NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding. The facilitator notes below will guide you as to the recommended time to run the animation.*

EXPLAIN THAT cohesive setting is associated with the glass transition temperature (Tg) of the wool.

REMIND participants that the glass transition temperature is the temperature at which protein molecules rapidly become more mobile and the fibre is most easily deformed. At glass transition the inter-molecular bonds restricting the relative movement of protein molecules become significantly weaker.

NOTE: This DOES NOT include the strong disulphide bonds.

REINFORCE that, as discussed in *Module 3: The physics of the wool fibre* (and shown on the slide), the glass transition temperature of wool is affected by its moisture content. The higher the moisture content of wool, the lower the glass transition temperature. Wet wool at room temperature (about 20ºC) is above its glass transition temperature.

EXPLAIN THAT cohesive set is most effectively formed when the wool fibres are deformed above their glass transition temperature and released below the glass transition temperature.

Cohesive set is lost (the wool fibre 'relaxes') when the wool is taken back above its glass transition temperature.

Wool may be cohesively set in steam or by wetting and drying the wool (as shown on the slide).

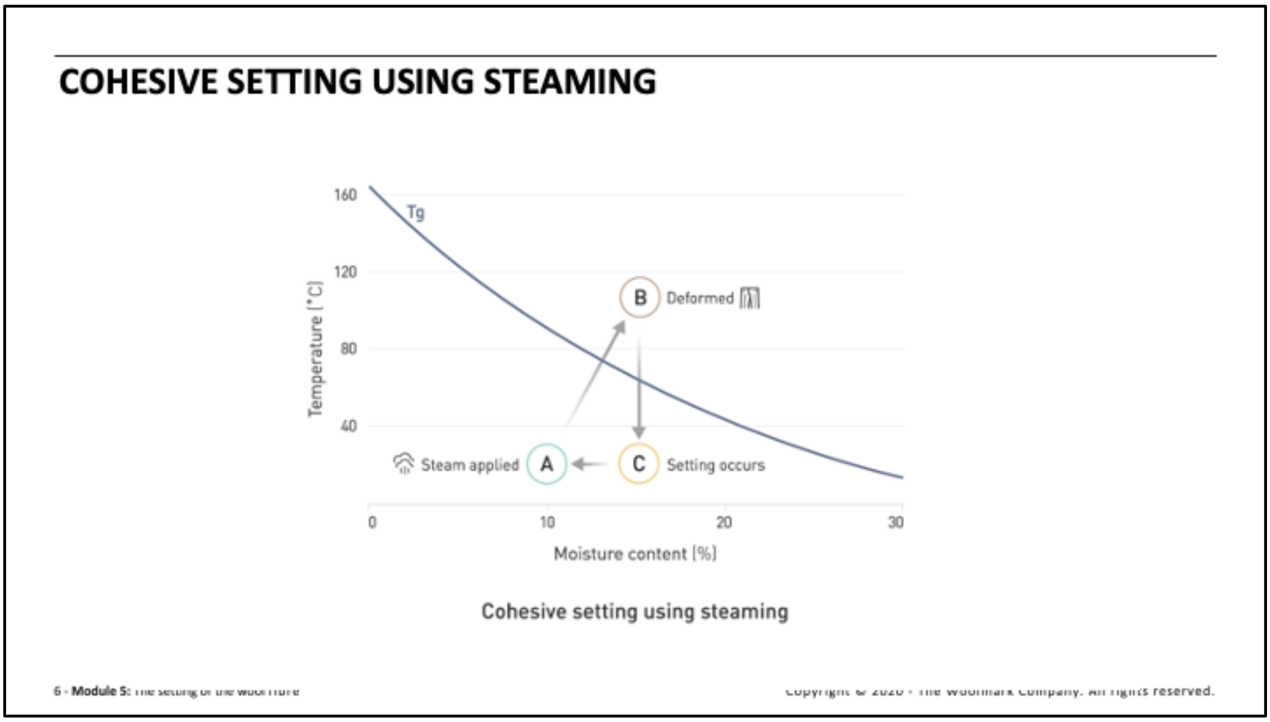
PLAY THE ANIMATION as you explain that cohesive set can be formed when a fibre is 'wet out' in water as illustrated in the animation. In this instance the fibre is deformed and held in the deformed state while it is dried and then cooled. (if necessary). Cohesive set imparted in this way stays while the fibres remain dry, however it is lost if the fibres are wet.

NOTE: These conditions are also used in 'cohesive setting' of human hair when wet hair is styled during blow drying. If the blow-dried hair gets wet the style is lost.

REFER to the diagram on the slide and explain that it shows the temperature profile of wool when cohesive set is formed by wetting and drying wool.

EXPLAIN THAT the solid curve shows the glass transition temperature of wool as the moisture content of wool increases.

- At point A the fibre is put into water while the temperature is maintained at about 25ºC, which brings the fibre 'above' the glass transition temperature (point B).
- At point B the fibre can be deformed into a new shape.
- Following deformation the fibre is dried using heat to a point at which it falls below the glass transition temperature (point C). Point C is below the glass transition temperature, so the fibre remains in the new shape as long as the fibre remains dry.



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NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding. The facilitator notes below will guide you as to the recommended time to run the animation.*

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REINFORCE THAT the previous slide illustrated how wool can be cohesively set by wetting and drying.

PLAY THE ANIMATION as you explain that it illustrates cohesive setting of wool using steam.

INDICATE THAT, as before, the solid curve shows the glass transition temperature of wool as the moisture content of the fibre increases.

- At point A the fibre is placed in a steamer (where both moisture content and temperature of the fibre are increased). This causes the fibre to rise above the glass transition temperature (Point B) where it can be deformed into a new shape.
- As the fibre cools to point C, it falls below the glass transition temperature, 'setting' fibre in the new shape while moisture and temperature conditions are such that the fibre remains below the glass transition temperature.

EMPHASISE THAT cohesive set cannot form in wet wool (>30%). It is already above its glass transition temperature.

COHESIVE SETTING BELOW GLASS TRANSITION TEMPERATURE

Cohesive set can be imparted even below the glass transition temperature (Tg) if the time (by a factor of 10) or conditions of setting greatly exceed the time or conditions of release (relaxation).

7 - **Module 5:** The setting of the wool fibre

EXPLAIN THAT cohesive set can be imparted below the glass transition temperature if the time or conditions of setting greatly exceed the time or conditions of release. This is because, even below the glass transition temperature, protein molecules can move, albeit slowly. As a result, the fibres can be set even below the Tg as long as they are deformed for a long time.

DEMONSTRATION — COHESIVE SET (continued)
ASK *the participants who are sitting on the folded fabric samples to remove their samples from the bags and hold the unfolded samples so the group can compare the creases. Ask the volunteers to describe what they see.*

REFER *to the participants' predictions recorded earlier in the lecture, acknowledge their observations and summarise by outlining that:*

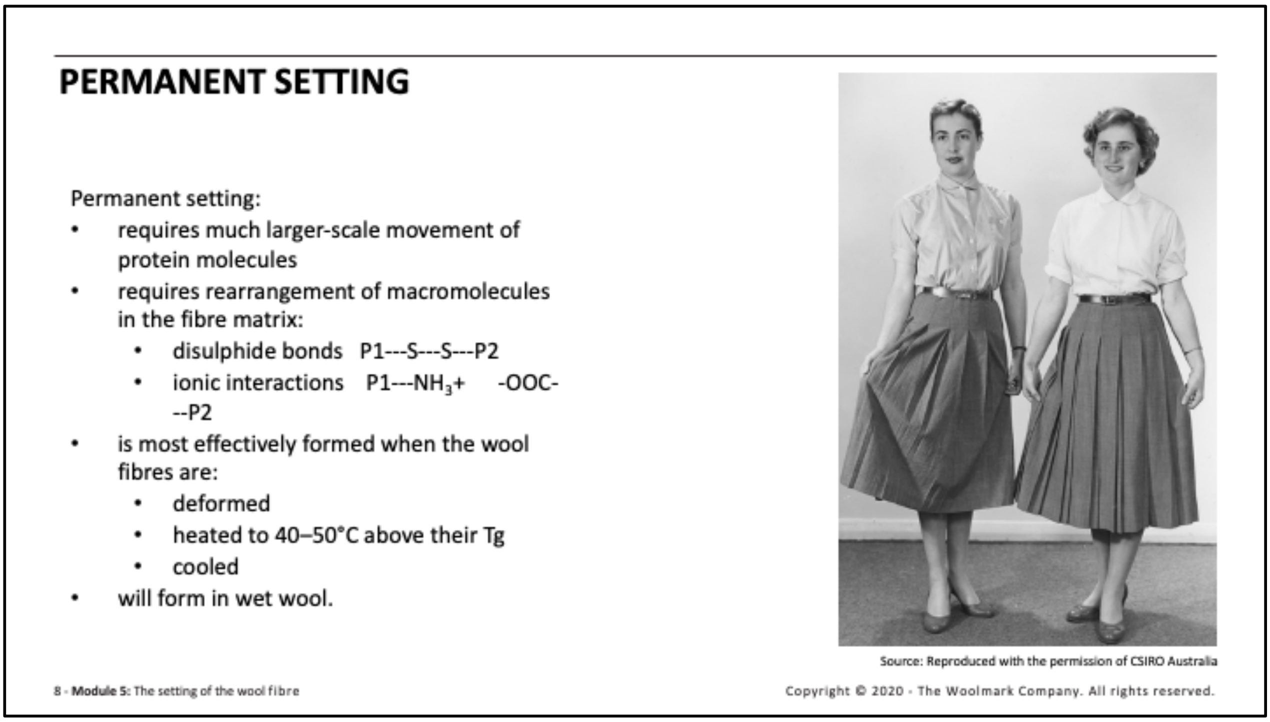
- *cohesive set in the wet wool (Sample A) was small – above the glass transition*
- *cohesive set in the very dry wool (Sample C) was small – too far below the glass transition*
- *cohesive set in the conditioned wool was more creased (Sample B).*

ASK *participants to explain the reasons for the differences observed.*

ACKNOWLEDGE *responses.*

EMPHASISE THAT cohesive set can be imparted, even below the Tg (for example, with bodyheat as in this demonstration), if the time or conditions of setting greatly exceed the time or conditions of release (e.g. wrinkling in wear).

ENCOURAGE students to observe the creasing behaviour of the different fabrics in their own clothing as a result of sitting during the lecture.



INDICATE THAT permanent setting requires a much larger-scale movement of protein molecules in the matrix regions of the fibre than cohesive setting.

EXPLAIN THAT it also requires rearrangement of the covalent crosslinks (disulphide bonds) between the macromolecules in the matrix regions of the fibre and the ionic crosslinks must also re-arrange.

BRIEFLY REMIND participants of the two different bonds, which were covered in *Module 4 The chemistry of the wool fibre*:

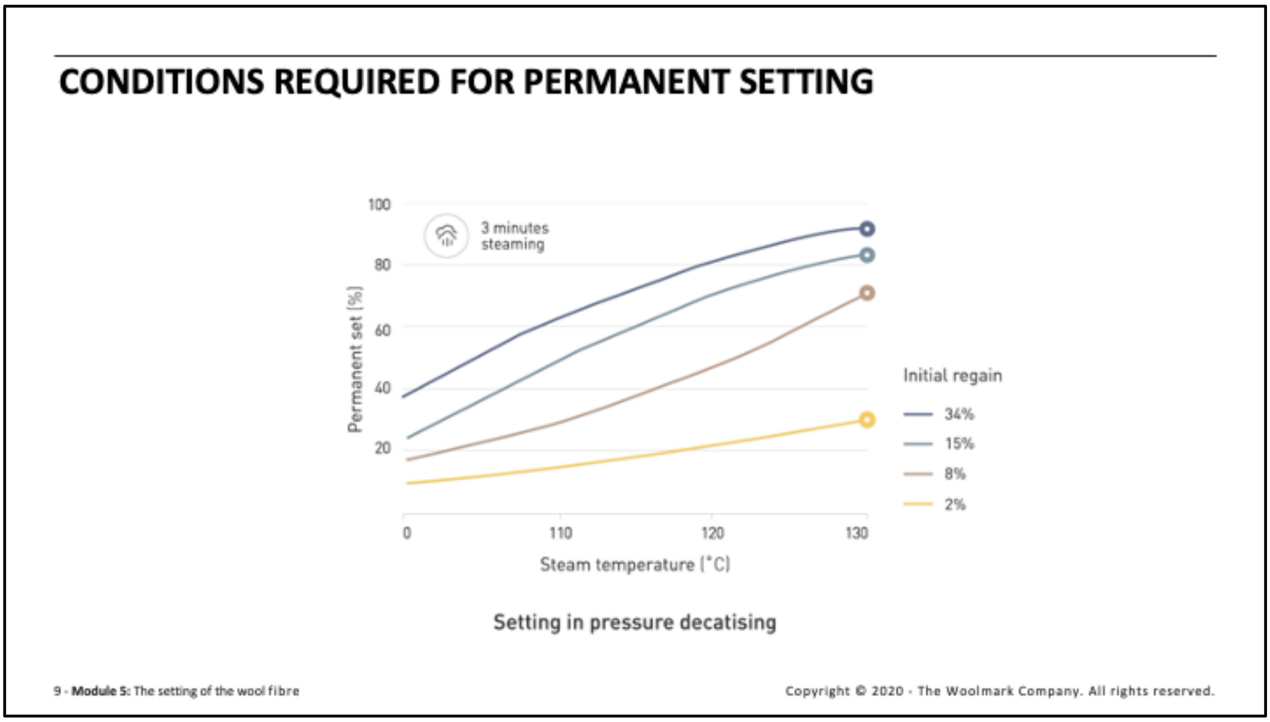
- Disulphide bonds: P1—S—S—P2
- Ionic crosslinks: P1—NH_3+ –OOC—P2

EXPLAIN THAT permanent set is most effectively formed when the wool fibres are deformed and heated to temperatures 40–50ºC above their glass transition temperature and then cooled.

NOTE THAT you will cover conditions required for permanent setting on the next slide.

POINT OUT that permanent set will form in wet wool and it is stable to 'wetting out'.

NOTE THAT permanent set is equivalent to having 'a perm' (permanent wave) in hair or having your hair chemically straightened.



NOTE TO FACILITATOR: *The graph on this slide is animated to enhance participant understanding. The facilitator notes below will guide you as to the recommended time to run the animation.*

REINFORCE that the temperatures required to achieve permanent set also depend on the moisture content of the fibre.

- In water a temperature >70°C is required
- Conditioned wool (i.e. wool at equilibrium with the surrounding relative humidity) requires temperatures >100°C
- Dry wool requires temperatures >200°C.

PLAY THE ANIMATION participants to the figure on the slide and explain that it illustrates:

- the amount of permanent set increases with the temperature of setting
- the amount of permanent set increases with a higher initial moisture content of the fibre (it is impossible to get high levels of permanent set In dry fibre even at 130ºC).

EXPLAIN THAT during processing it is desirable to achieve permanent set as quickly as possible.

NOTE THAT ideally a finisher would like to permanently set wool continuously, in both wet and dry operations with setting times of less than 30 seconds.

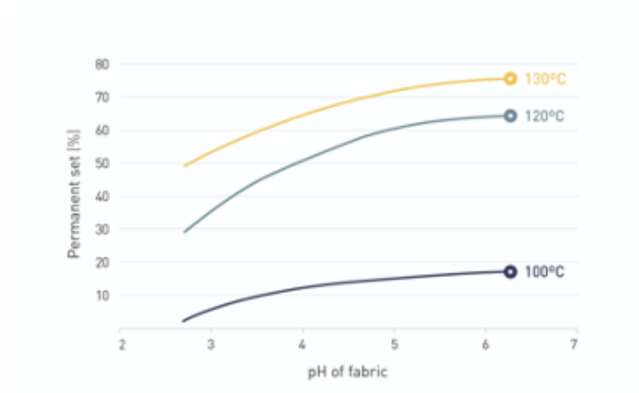
EXPLAIN THAT the temperatures required to achieve significant levels of permanent set in such short times are very high (>130ºC)

EFFECT OF pH ON PERMANENT SETTING

The pH of the fabric, and the setting solution, affect the formation of permanent set.

- At low pH (<3) the rate of formation of permanent set is slow (acid conditions reduce the number of ionised thiol groups).
- At higher pH (>6) the rate of formation of permanent set is faster (alkaline conditions increase the number of ionised thiol groups).

$$\text{P---S}^- \underset{\text{Alkali}}{\overset{\text{Acid}}{\rightleftharpoons}} \text{P---SH}$$



10 - **Module 5:** The setting of the wool fibre

***NOTE TO FACILITATOR:** The graph on this slide is animated to enhance participant understanding. The facilitator notes below will guide you as to the recommended time to run the animation.*

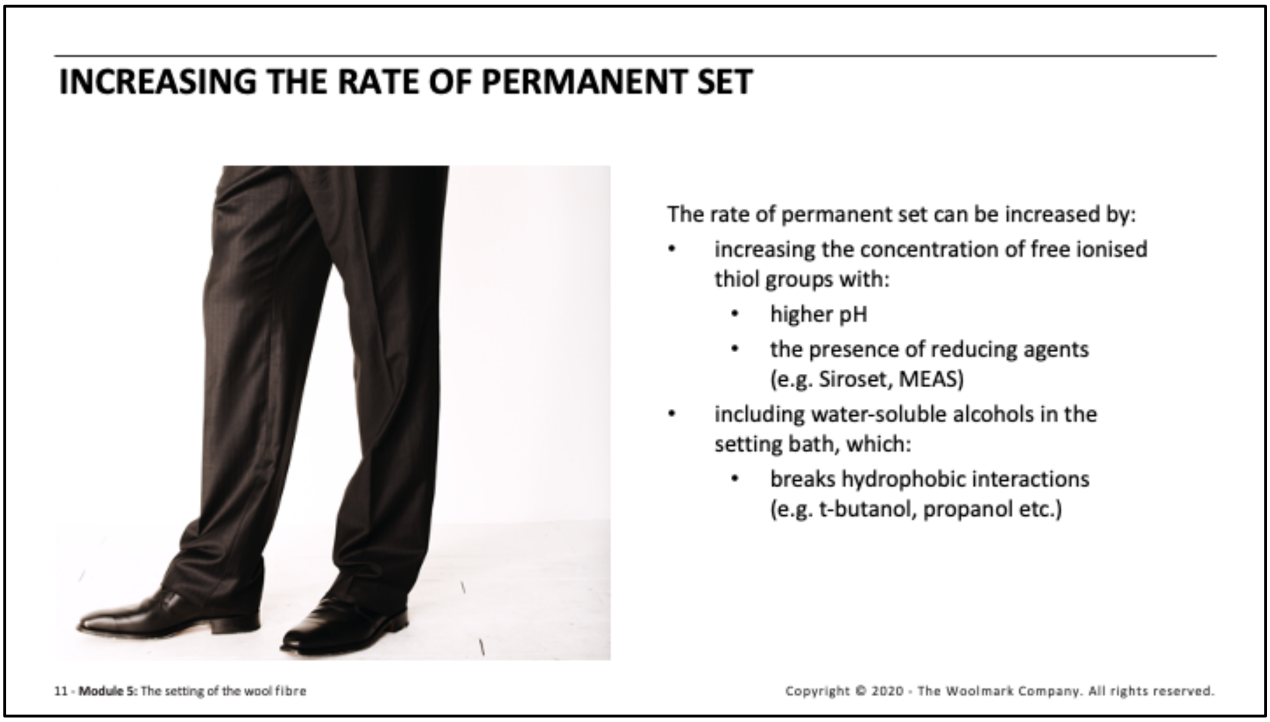
EXPLAIN THAT the amount of permanent set depends on the amount of disulphide interchange that occurs between fibres.

REMIND participants that disulphide interchange only occurs in the presence of free thiol anions (SH-) or free hydrogen sulphide (H_2S/HS-). This is affected by the pH of the fabric and the setting solution.

EXPLAIN THAT at low pH (acid) conditions ionised thiols react with hydrogen ions to form un-ionised thiol groups, which do not catalyse thiol disulphide interchange and prevent permanent set.

POINT OUT that conversely, permanent set increases at higher fabric pH or pH of the setting solution (alkaline conditions).

PLAY THE ANIMATION as you explain that it illustrates the relationship between pH of the fabric and the degree of permanent set attained in three minutes.



EXPLAIN THAT it is possible to increase the rate of permanent set by increasing the concentration of free ionised thiol groups, which catalyse thiol-disulphide interchange.

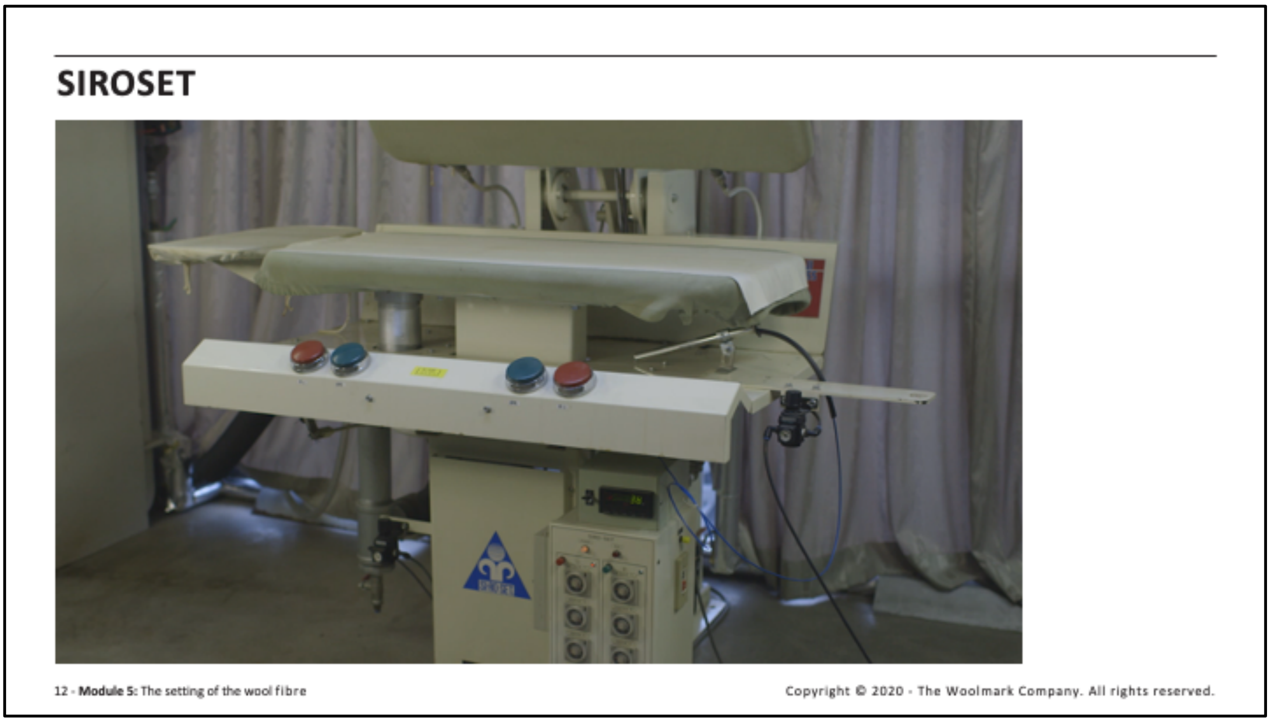
OUTLINE that this can occur either by:

- increasing pH
- treating the wool with a reducing agent (e.g. Siroset, MEAS).

EXPLAIN THAT the widely-used 'Siroset' process uses a reducing agent to facilitate permanent setting of creases and pleats in woven apparel (e.g. the suit trousers shown on the slide).

EXPLAIN THAT including water-soluble alcohols in the setting bath (e.g. propanol or t-butanol etc.) disrupts hydrophobic crosslinks and increases the rate of permanent setting.

REINFORCE that the greater the number of free ionised thiol groups, the faster the rate of permanent set.



BEFORE PLAYING the video, explain that it shows the permanent setting of men's trousers using the Siroset process.

EXPLAIN THAT the setting agent shown in the video is a mixture of:

- a reducing agent
- a chemical to control pH
- a wetting agent.

ENCOURAGE participants to notice the difference in the volume of setting agent that is applied to the creases of the trousers and the body of the trouser legs during the video.

PLAY *the video (5:34)*

WAIT *until the end of the video and then ask participants to explain this difference.*

ACKNOWLEDGE *participant responses and provide the answer if participants do not offer the correct response.*

ANSWER: *The extra application of the setting agent on the area of the creases in the trousers is designed to maximise the levels of permanent set on these key regions of the trousers.*

ASK *participants if they have any questions about the process of imparting permanent set before you move on to discuss the challenge of inhibiting permanent set during the dyeing process.*

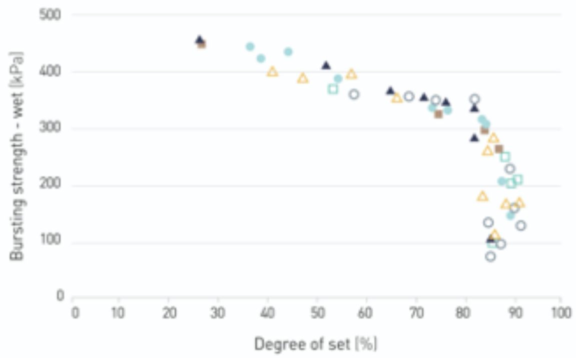
ADDRESS *any questions in a timely manner.*

OVERSETTING OF WOOL

Excessive levels of permanent set using chemical agents:

- melts the crystalline regions
- damages fabric properties.

PERMANENT SET IMPARTED (%)	ENERGY OF MELTING (J/GM)
0	20.8
41	20.6
58	18
88	10.4
86	2.7
90	5.6



Effect of permanent set on bursting strength

EXPLAIN THAT there is a risk of 'oversetting' of wool during processing.

To achieve high levels of permanent set (>80%), severe disruption of the disulphide bonds is required, which disrupts the crystalline regions of the fibre.

INDICATE THAT excessive levels of permanent set using chemical agents:

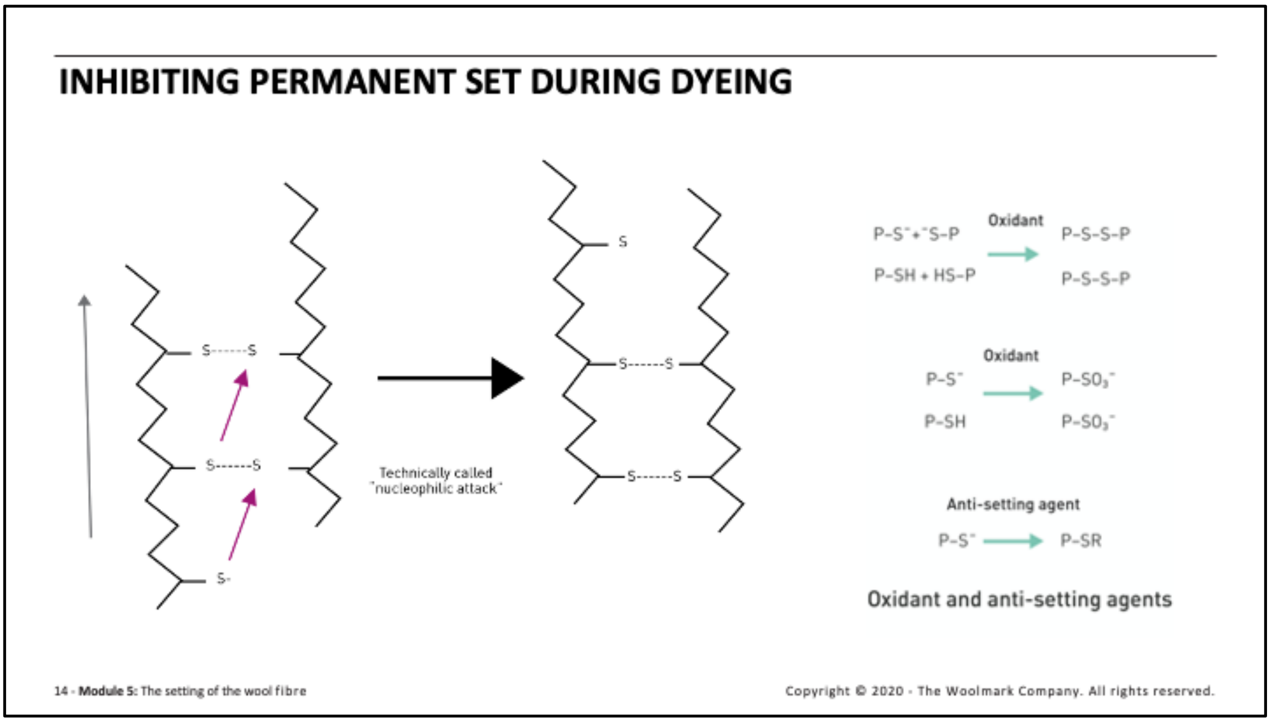
- melts the crystalline regions of the fibre
- damages the fabric properties.

REFER to the table on the slide, which demonstrates that at high levels of set there is a reduction in the energy of melting of the fibre (shown in the table) indicating a disruption of the crystalline regions of the fibre.

EXPLAIN THAT the graph on the slide shows that above 80% permanent set there is a rapid decrease in the wet (bursting) strength of the fibres (shown in the figure).

NOTE THAT bursting strength is a good indicator of fibre damage.

EXPLAIN THAT above 80% permanent set there also is a significant increase in the stiffness (bending rigidity) of the set fabric.



EXPLAIN THAT inhibiting permanent setting during dyeing, (by preventing disulphide interchange using anti-setting technology) is carried out to reduce damage to the wool fibres during the process.

EXPLAIN THAT anti-setting technologies to minimise permanent setting during the dyeing process were commercially introduced during the mid 1990s.

INDICATE THAT two methods (shown on the slide) have been used in the past:

- Oxidants can be included in the dyebath, which remove free thiol groups.
- Substantive electrophilic compounds (anti-setting agents) can be included in the dyebath, which react with free thiol groups.

EXPLAIN THAT currently available technology relies on the addition of:

- a hydrogen peroxide activator and a small quantity of hydrogen peroxide to the dyebath
- addition of maleic anhydride or a maleic acid ester.

INDICATE THAT the auxiliary and/or hydrogen peroxide are added at the start of dyeing and the process is then carried out as normal.

NOTE: Peroxide can only be used with dyes that are not sensitive to oxidation.

EXPLAIN THAT both products reduce the number of free ionised thiol groups in the fibre and, in turn, the rate of permanent setting.

INDICATE THAT formaldehyde also reacts with free thiols, so formaldehyde release agents can also be introduced to reduce permanent setting.

EXPLAIN THAT high levels (>3.0%) of reactive dyes have effective anti-setting properties so additional agents are unnecessary.

NOTE THAT dyeing at low pH (pH 2–4), with acid levelling or 1:1 pre-metallised dyes, also reduces the permanent setting action of the dyebath.

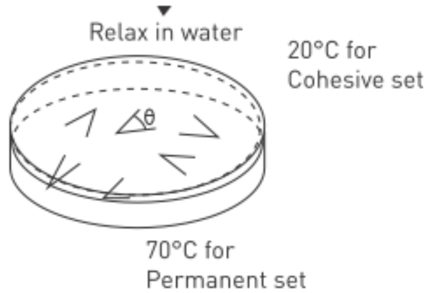
SUMMARY — MODULE 5

Setting requires relative movement of the protein molecules or stress relaxation of deformed fibres

Three types of set in wool:

1. cohesive
2. temporary
3. permanent

Types of set can be distinguished by wetting out yarn snippets at 20°C and at 70°C.



15 - **Module 5:** The setting of the wool fibre

SUMMARISE this module by reinforcing that setting of wool fibres (and fabric) requires relative movement of the protein molecules in the fibre.

REMIND participants of the three types of set that can be achieved in wool:

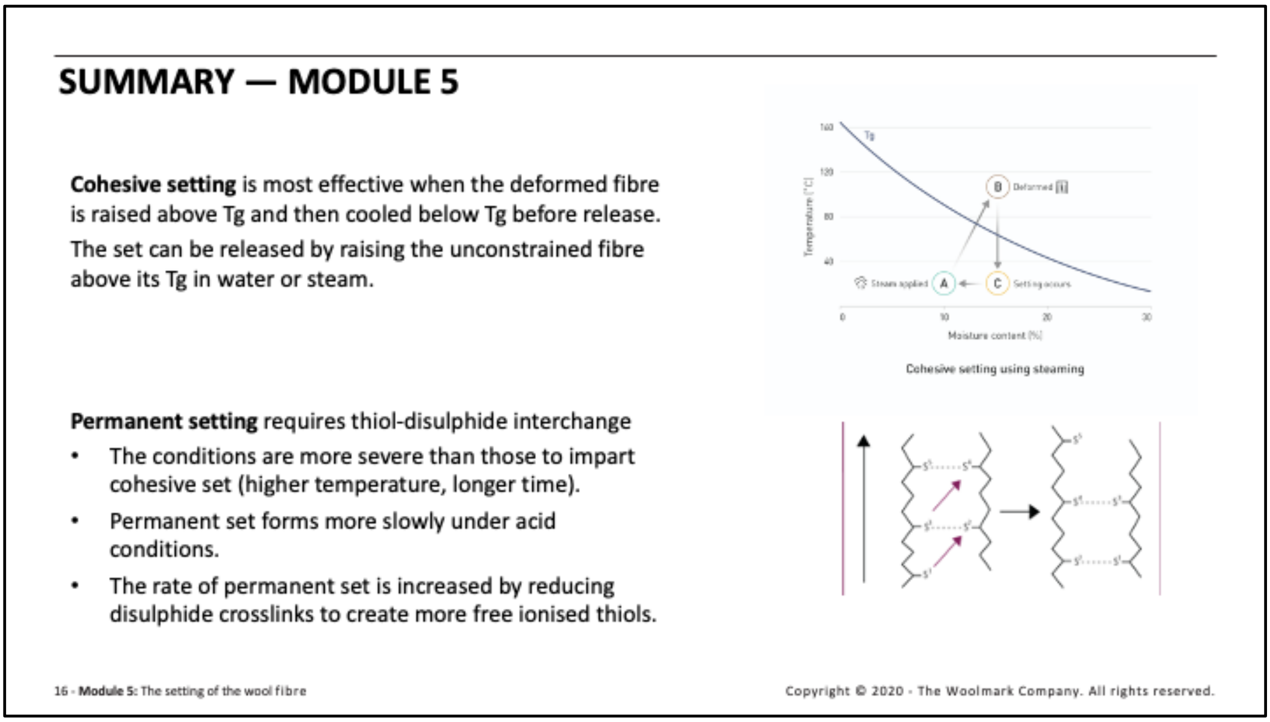
- cohesive set
- temporary set
- permanent set.

REINFORCE THAT the various types of set can be distinguished by 'wetting out' yarn snippets for 30 minutes at 20ºC or 70ºC.

Cohesive set is lost when the fibres are wet out at 20ºC for 30 minutes.

Temporary set is stable to water at 20ºC but is lost when the fibre is immersed at 70ºC for 30 minutes.

Permanent set is measured as set stable to release in water at 70ºC for 30 minutes.



REMIND participants that cohesive set is associated with the glass transition temperature (Tg) of the wool fibre and is achieved by steaming or by wetting and re-drying the fibre. Cohesive setting is most effective when the deformed fibre is raised above Tg and then cooled below Tg before release.

REINFORCE that cohesive set is released by raising the unconstrained fibre above its glass transition temperature:

- in water
- In steam.

REITERATE that permanent set requires disulphide interchange, which is formed at high temperatures and catalysed by ionised thiol groups within the fibre.

REINFORCE that the conditions to impart permanent set are more severe (with a greater risk of damage to the fibre) than those to impart cohesive set (i.e. higher temperatures for a longer time).

REMIND participants that:

- permanent set forms more slowly under acid conditions
- permanent set will form more quickly in the wet fibre.

The rate of permanent setting is increased by reducing disulphide crosslinks to create more free ionised thiols.

The rate of permanent setting is reduced by oxidising free thiols or reacting with an anti-setting agent, which reacts with free thiols.

***ASK** participants if they have any further questions about the content covered in this module.*

***ALLOW** time for questions and discussion before proceeding to the final slide and closing the lecture.*

INFORM participants of the time and location for the next lecture — *Module 6 The shrinkage of wool products* — and ensure they read through the relevant notes in their Participant Guides before attending the lecture.

ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in today's lecture.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

MODULE 6

THE SHRINKAGE OF WOOL PRODUCTS

RESOURCES —
MODULE 6: THE SHRINKAGE OF WOOL PRODUCTS

Contained in the *Wool fibre science* Demonstration kit you will find the following resources for use as you deliver **Module 6: The shrinkage of wool** products:

- knitted fabric
- felted and unfelted sock
- tightly woven fabric (e.g. suiting fabric)
- loosely knitted fabric (e.g. sweater)
- felted (non-woven) fabric.

Additional resources to be sourced by the facilitator include:

- steam iron
- towel
- felted and unfelted sock
- a stack of plastic cups or yarn cones
- lint brush.

WELCOME participants to Module 6 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The shrinkage of wool products*.

EXPLAIN THAT this module will explore dimensional change (otherwise known as shrinkage or consolidation) in wool products and will cover:

- what causes dimensional change
- two key types of dimensional change (i.e. relaxation shrinkage and felting shrinkage) and the differences between them
- methods of preventing felting shrinkage.

INFORM participants that by the end of this module they will be able to:

- distinguish between the two different types of dimensional change (i.e. relaxation shrinkage and felting shrinkage)
- describe the consequences of each type shrinkage
- explain the five factors that contribute to the felting shrinkage of wool
- describe the management of each type of shrinkage
- describe methods of treating wool to prevent felting shrinkage and the mechanisms involved.

RESOURCES REQUIRED FOR THIS MODULE

- *knitted fabric*
- *felted and unfelted sock*
- *tightly woven fabric (e.g. suiting fabric)*
- *loosely knitted fabric (e.g. sweater)*
- *felted (non-woven) fabric.*
- *steam iron*
- *towel*
- *felted and unfelted sock*
- *a stack of plastic cups or yarn cones*
- *lint brush.*

SHRINKAGE (CONSOLIDATION) IN WOOL FABRIC

Relaxation shrinkage

Felting shrinkage

3 - **Module 6:** The shrinkage of wool products

EXPLAIN THAT shrinkage that occurs during finishing is sometimes called 'consolidation'. Is an important part of finishing some types of fabric.

ASK *participants to raise their hands if they have experienced shrinkage in any wool products. Select a participant to describe their experience.*

ACKNOWLEDGE RESPONSES *before you continue.*

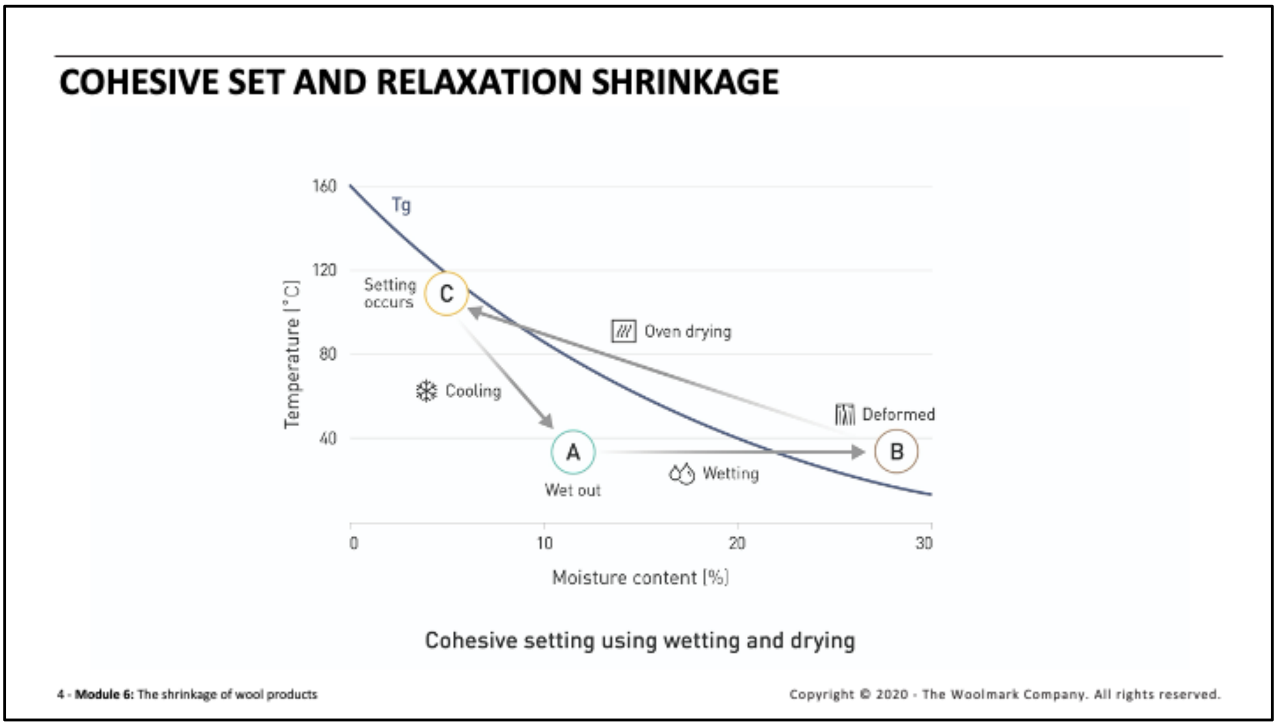
EXPLAIN THAT it is important to distinguish between the two different types of shrinkage in wool fabrics and garments.

Relaxation shrinkage:

- is the dimensional change that can occur when a yarn or fabric is allowed to relax by immersing it in water, or exposing it to steam
- happens when residual stresses and strains in wool are allowed to relax
- can be reversible, under specific conditions. The wool product can be stretched to a new shape although that shape will also not be permanent when immersed in water.

Felting shrinkage:

- is the shrinkage that occurs when a damp or wet fabric is subjected to mechanical action, which entangles the fibres
- is seen as matting or thickening of the fabric in addition to a drastic reduction in dimensional size
- with extended mechanical action, can result in a significant reduction in the size of the sample or product
- is not reversible.



EXPLAIN THAT cohesive setting is responsible for relaxation shrinkage.

REFER TO the graph on the slide as you briefly review the concept of cohesive set and ask participants if they can recall from the previous lecture under what conditions cohesive set will be lost (i.e. relaxed).

ACKNOWLEDGE RESPONSES before you continue.

DEMONSTRATION — RELAXATION SHRINKAGE

Resources required:

- *Knitted wool fabric or garment (e.g. a long-sleeved t-shirt).*
- *Measuring tape or ruler*
- *Iron with a steam setting and ironing board or suitable alternative*
- *Water (for iron)*

Measure and record the length of the original fabric.

Stretch the sample and iron using steam.

Hold up sample and measure new set length (cohesive set).

Re-steam the sample (without making contact with the iron itself) and observe length changes (relaxation).

***NOTE:** Length change is relaxation shrinkage caused by a loss of cohesive set.*

EXPLAIN THAT fabric is often stretched during finishing, or other handling operations, and cohesively set. If fabric is held in stretched form by 'cohesive set', when the fabric is then relaxed in water or steam, the cohesive set is lost and the fabric shrinks.

REINFORCE THAT the figure on the slide shows the relationship between the temperature and the moisture content (or regain) of the wool fabric. The solid curve shows the glass transition temperature of wool as moisture content increases.

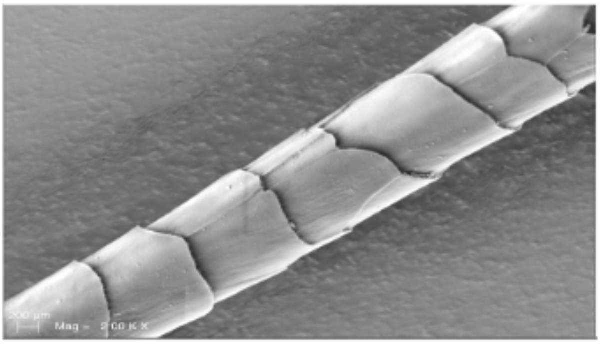
EXPLAIN THAT garments can also be stretched and distorted during wear.

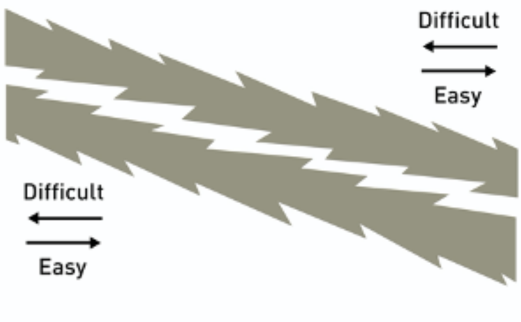
If the stretch or distortion is held (stabilised) by 'cohesive set', then when the fabric is subsequently relaxed in either water or steam:

- the cohesive set (and distortion) is lost
- the fabric shrinks back to its original state.

REINFORCE THAT this is 'relaxation shrinkage'.

FELTING SHRINKAGE





Individual wool fibres move more easily against each other in one direction than the other due to the composition of the overlapping cuticle cells (scales).

5 - **Module 6:** The shrinkage of wool products

EXPLAIN THAT felting shrinkage is caused by the physical structure of the wool fibre, which allows individual fibres to move more easily in one direction than in the other when agitated in water.

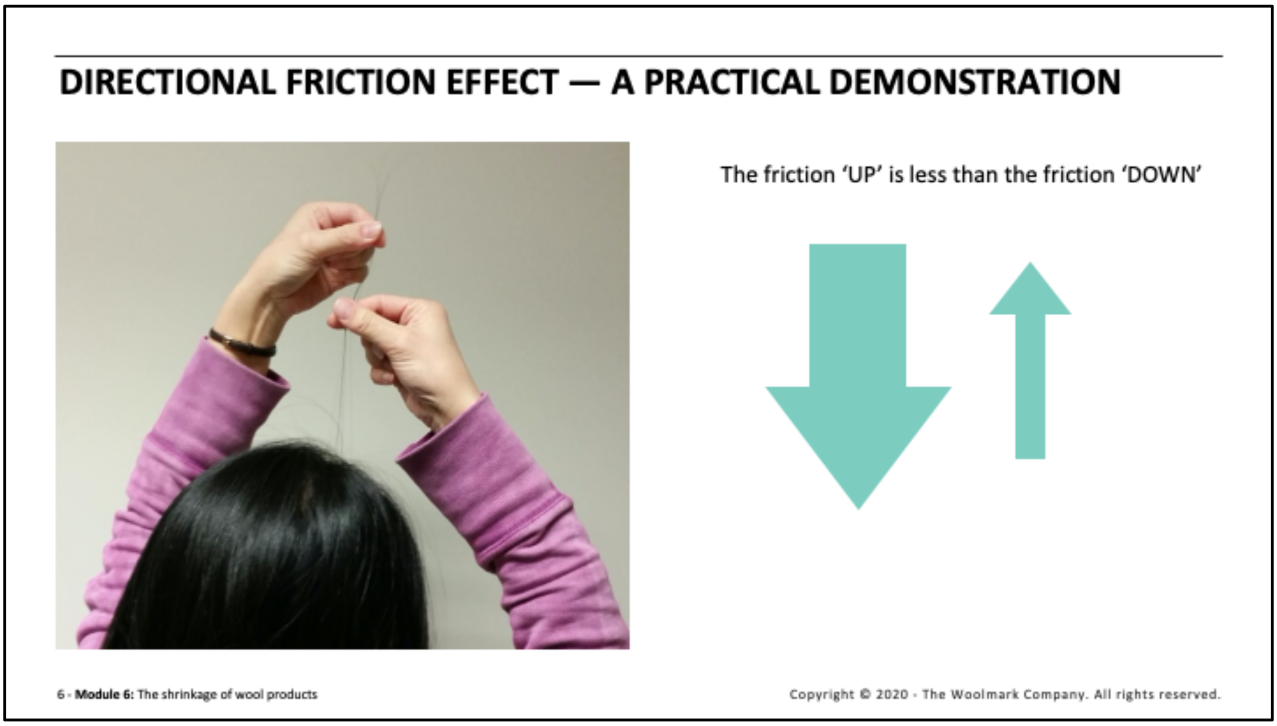
The ‘ratchet’ effect, is the difference in resistance or friction as a result of the overlapping scales moving against each other along the hair fibre.

REMIND participants this directional friction effect (DFE), discussed briefly *Module 2: The structure of wool fibres* is the cause of felting shrinkage in wool.

REINFORCE THAT the directional friction effect is a result of the ridges formed by the cuticle cells on surface of the wool fibre. The ratchet mechanism in felting shrinkage is a simple manifestation of the directional friction effect in wet wool when agitated, causing adjacent fibres to move relative to each other.

POINT OUT that wool must be wet or have high a regain (moisture content) to felt (the directional friction effect is much higher in wet wool as the scale edges ‘lift’ when the wool is wet).

EXPLAIN THAT the directional friction effect also inhibits the return of the fibres to their original position adjacent to other fibres.



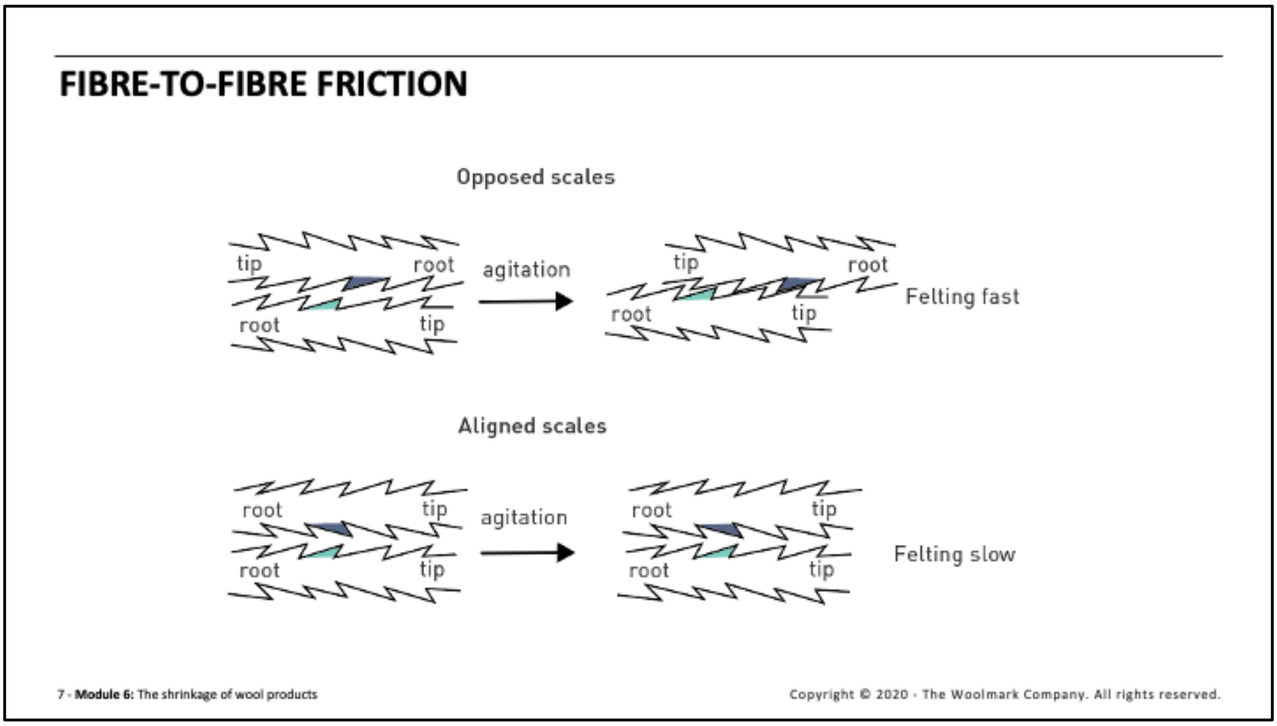
REMIND participants that, as demonstrated in *Module 2: The structure of wool fibres,* it is possible to feel the scales on the surface of our own hair fibres.

REINFORCE THAT these are similar to the scales responsible for the directional friction effect and felting shrinkage in wool.

ENCOURAGE participants to repeat this demonstration on their own hair.

NOTE THAT when exploring the directional friction effect on your own hair, it is more difficult to rub wet hair from tip to root. Wet hair is also more difficult to comb, unless it is tangled – then combing in any direction is difficult.

EXPLAIN THAT hair conditioners reduce friction on wet hair, but do not prevent felting because they do not affect the directional friction effect.



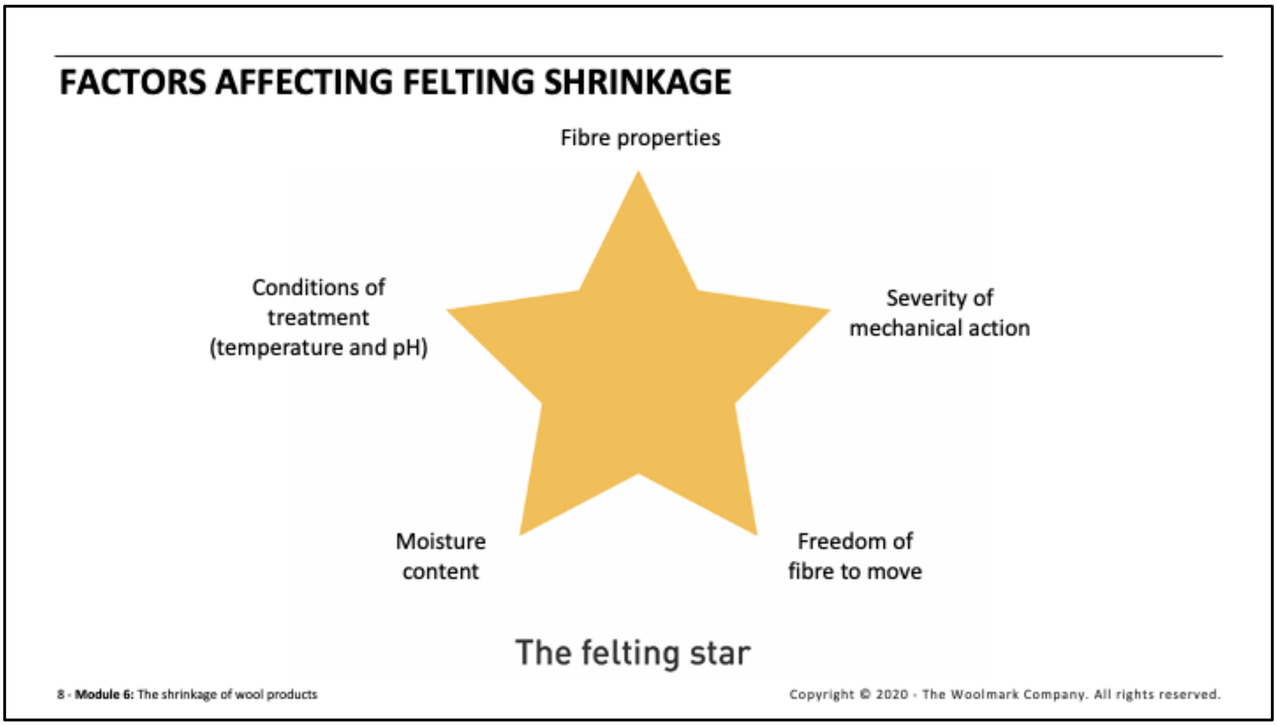
REFER TO the diagrams on the slide as you explain that there are various ways fibres can align and rub together, which can modify the impact on friction on felting shrinkage.

On the sheep's back the fibres are aligned so the impact of the directional friction effect is much reduced, so the fleece does not normally felt when it gets wet. Only when a sheep rubs their fleece on a fence post or tree while it is wet can the fibres in the fleece start felting.

EXPLAIN THAT during processing wool the root-to-tip direction of the fibres is random, so felting shrinkage occurs much more readily.

***ASK** participants if they have any questions about concepts of relaxation and felting shrinkage before you move on to discuss the felting shrinkage process in more detail.*

***ADDRESS** any questions in a timely manner.*

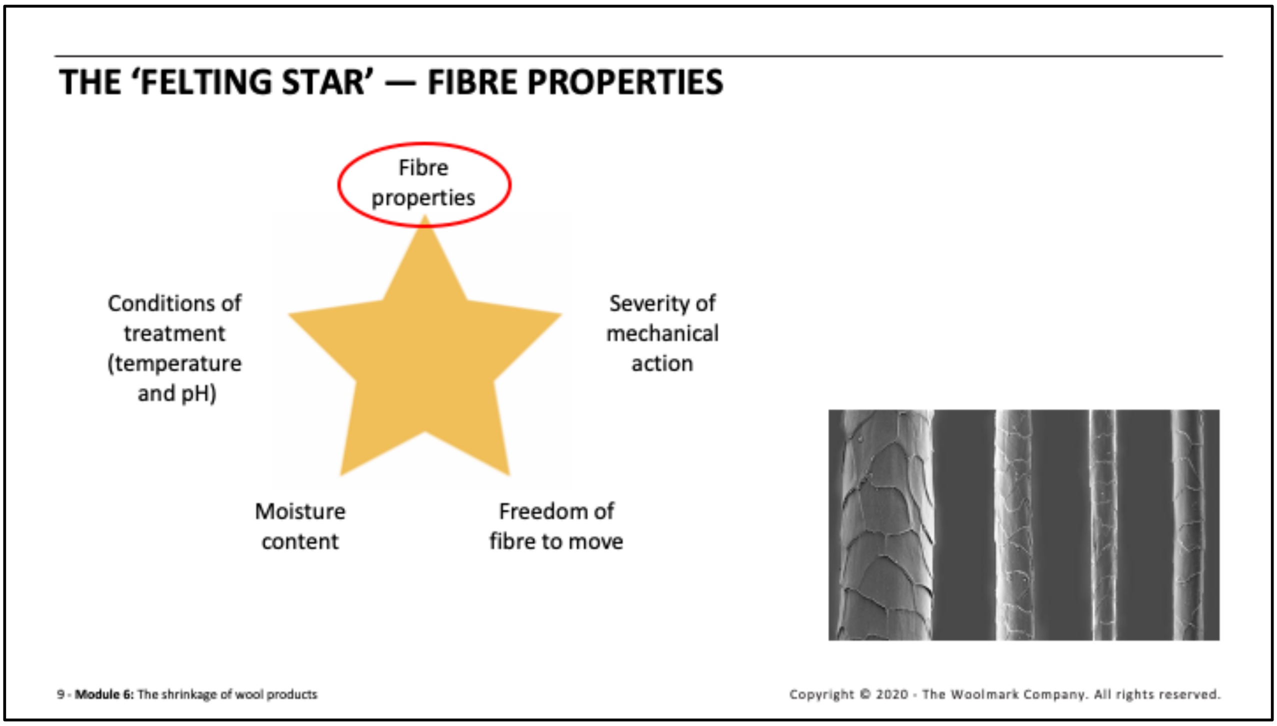


REINFORCE THAT felting shrinkage in wool requires moisture and mechanical agitation.

REFER TO the star on the slide and outline the factors that affect the rate of felting and form the five corners of the 'felting shrinkage star':

- fibre properties (frictional properties and pH of the wool fibre)
- severity of mechanical action
- freedom of fibre to move (yarn and fabric structure)
- moisture content
- conditions of treatment (temperature and pH).

EXPLAIN THAT you will review these five factors, one by one, in the following pages.



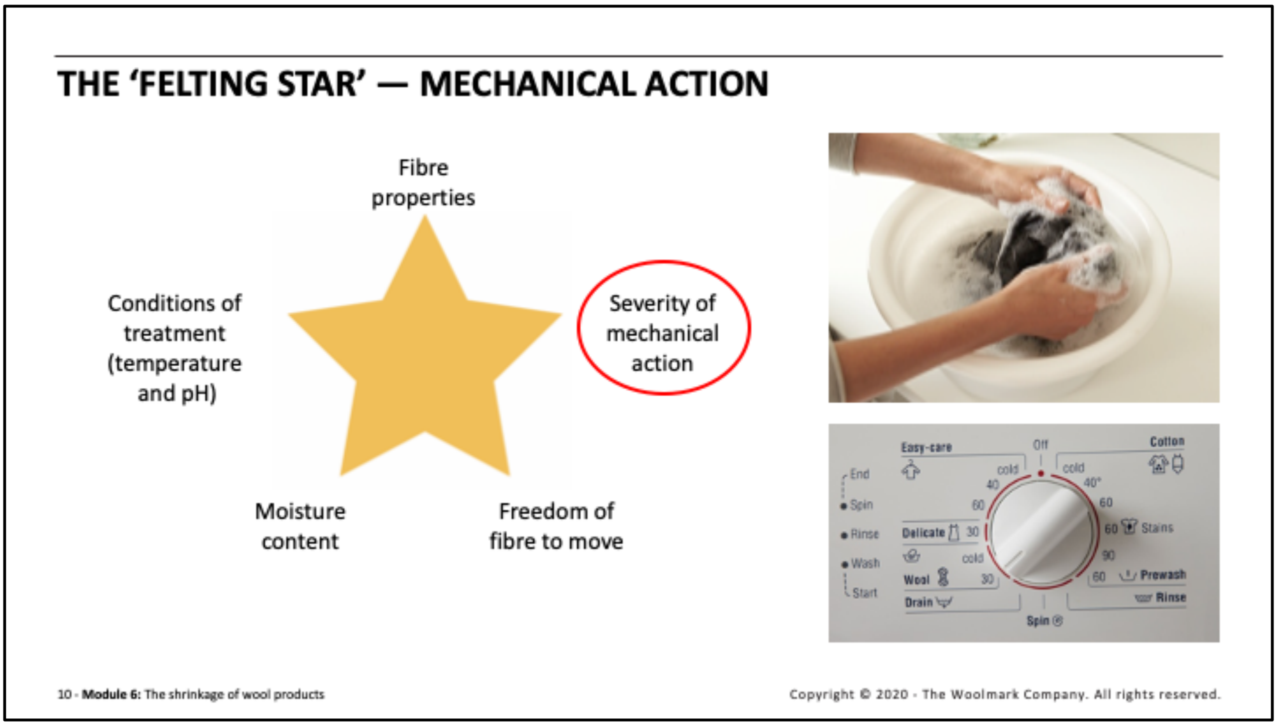
EXPLAIN THAT fine fibres are easily deformed and migrate (move relative to one another) more easily than broad fibres as they have larger surface areas with which they interact with each other. As such, fine wool felts more rapidly than broader wool types.

REFER TO the micrograph on the slide as you explain that on some animal fibres, and some wool types, the cuticle cells (scales) are more pronounced than on other fibre types.

EXPLAIN THAT this scale configuration affects the directional friction effect (DFE) and hence the felting shrinkage rate.

INDICATE THAT the directional friction effect is reduced if the cuticle cells are damaged. For example, some chemical treatments:

- reduce the directional friction effect
- lower the preferential movement of fibres in the root direction
- increase the friction between fibres but reduce the directional friction effect.

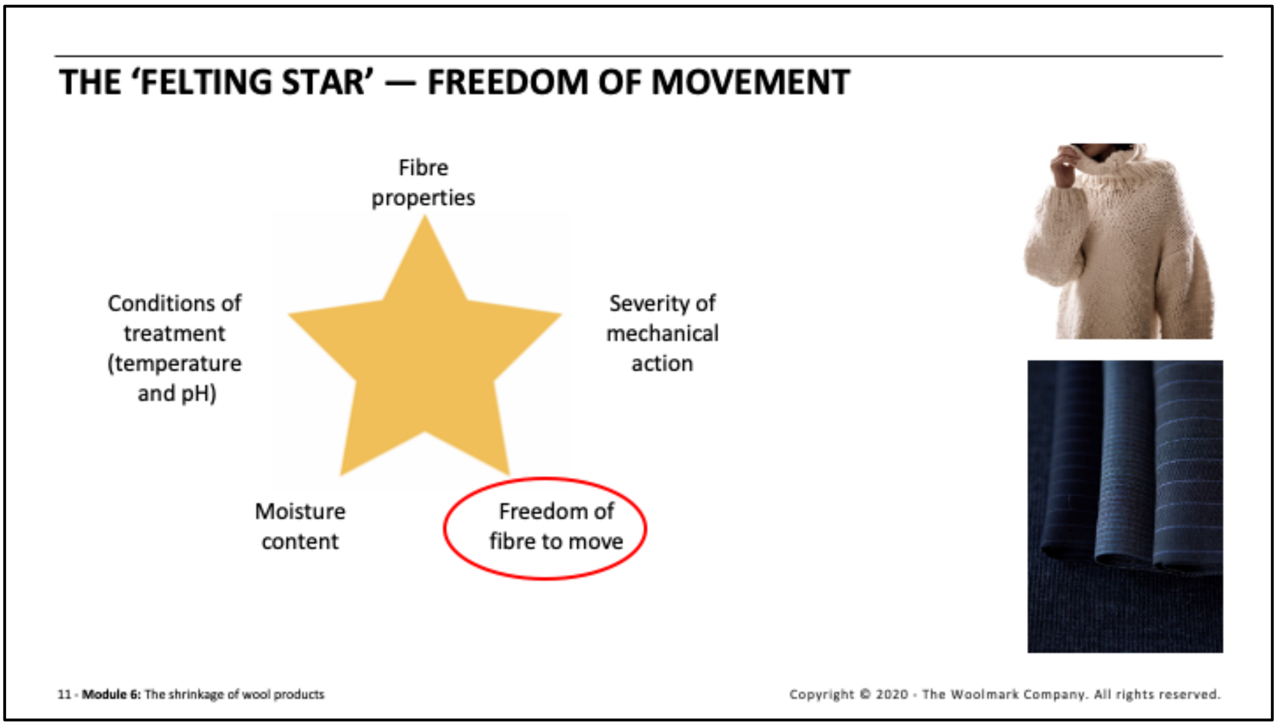


EXPLAIN THAT the more severe the mechanical action acting on wet wool, the more rapid the felting shrinkage.

PROVIDE the example that gentle hand washing reduces agitation compared with machine washing, and limits felting shrinkage.

INFORM participants that washing machine manufacturers now incorporate 'wool cycles' in their washing machines, which are gentle and limit the risk of felting shrinkage in wool products.

NOTE TO FACILITATOR: *If delivering this lecture to a Chinese audience indicate that Chinese washing machines can be particularly severe. Some Italian and Korean machines have low action cycles approved by The Woolmark Company.*



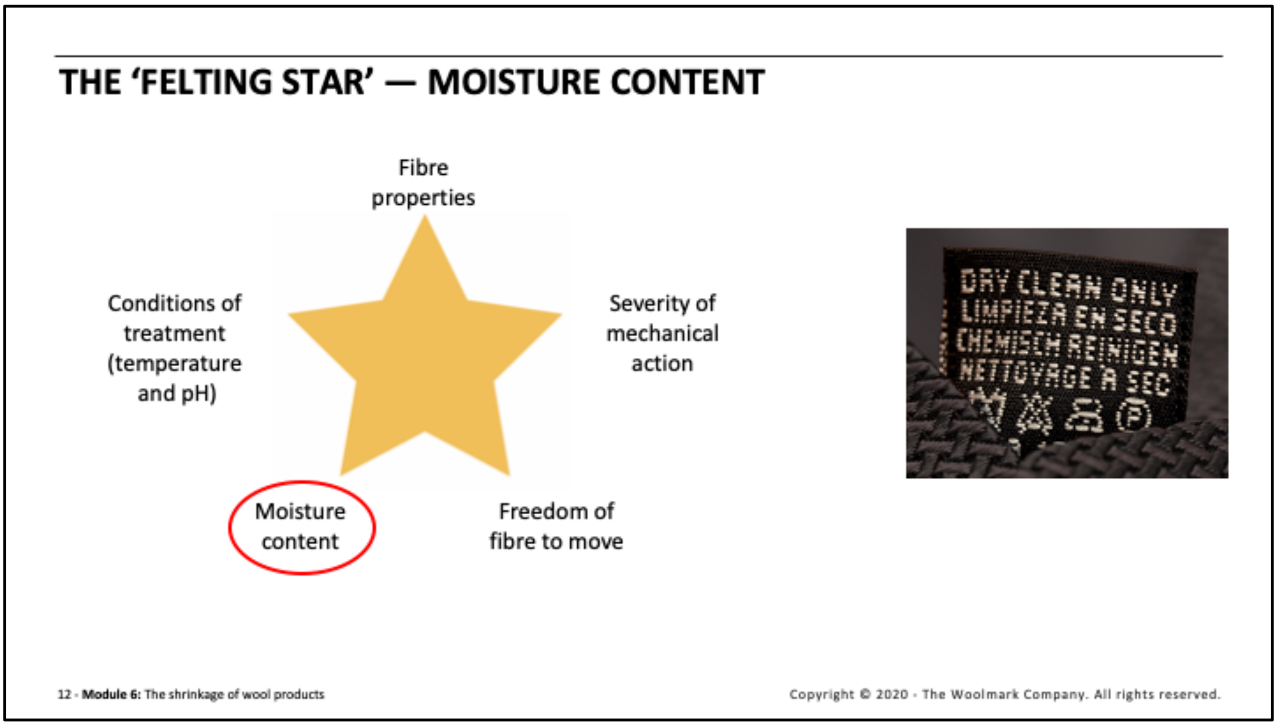
EXPLAIN THAT the freedom of wool fibres to move when subjected to mechanical agitation depends on the construction of the wool product (yarn, fabric, garment — knitted or woven) .

DEMONSTRATION — FREEDOM OF MOVEMENT

Resources required:

- *Tightly woven wool fabric (e.g. suiting fabric)*
- *Loosely knitted, heavyweight fabric (e.g. wool sweater)*

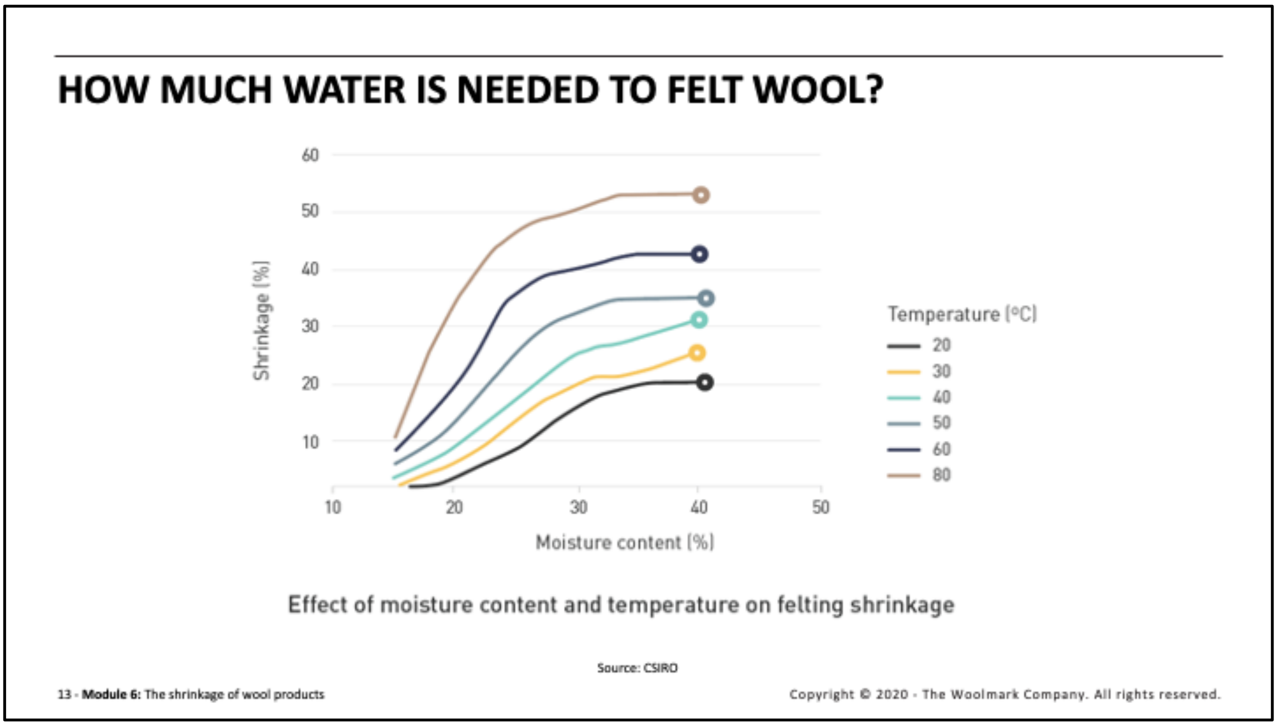
DISTRIBUTE *the two samples of wool fabric as you explain that short fibres (such as those used in heavyweight knitwear) have fewer points of constraint and can migrate (i.e. felt) more rapidly than longer, finer fibres. Fabric from low-twist yarns and loosely-woven or knitted fabrics also can felt more rapidly.*



REMIND participants that felting shrinkage only occurs if the fibres are wet, or have a high moisture content, and the cuticle scales are more pronounced or raised.

EXPLAIN THAT dry cleaning normally uses an organic solvent, which contains only a small amount of water. In the absence of sufficient water, felting shrinkage of wool does not occur.

POINT OUT that some dry cleaners add too much water to their machines so felting shrinkage can occur in delicate articles.



REFER TO the figure on the slide and explain that it illustrates how the rate of felting of wool increases with the amount of water used during dry cleaning (across a range of temperatures).

EXPLAIN THAT a dry cleaner will use water in the dry cleaning solvent to remove water-soluble soil and stains:

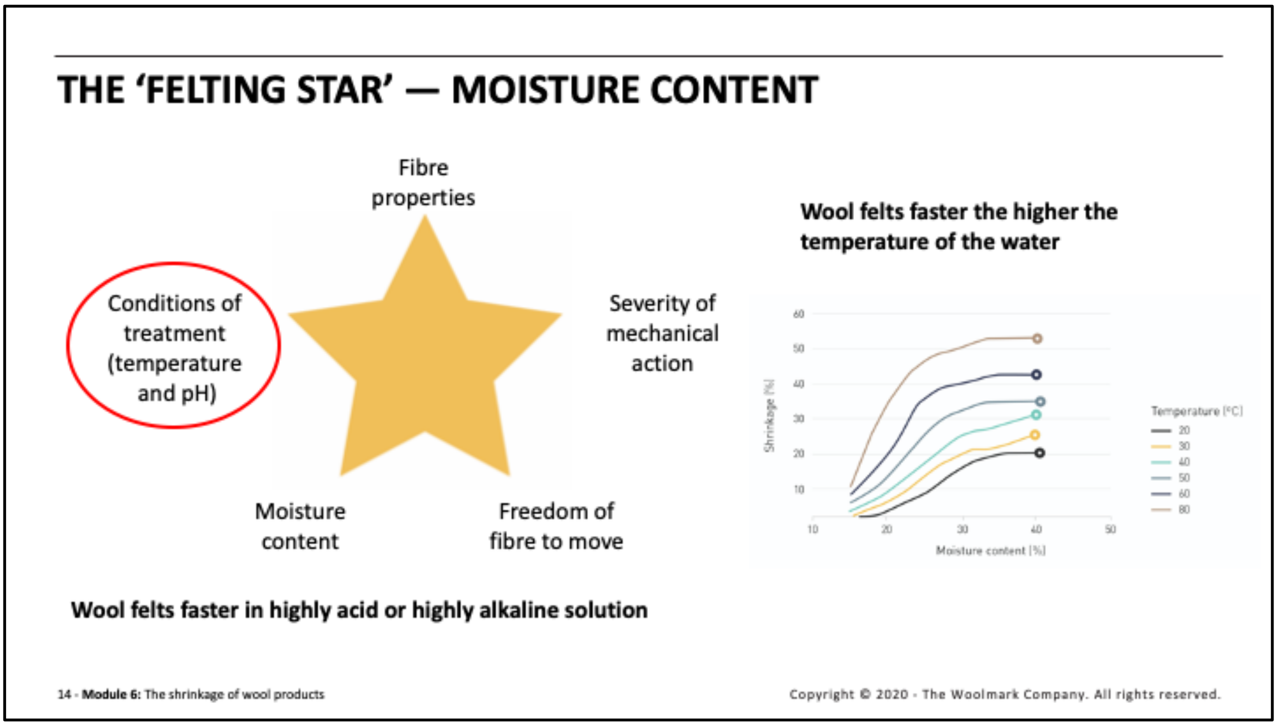
- Too little water – cleaning is inadequate.
- Too much water – delicate wool garments will felt.

INTRODUCE THE concept of 'dry felting' by explaining that dry felting is caused by mechanical action on 'damp' wool. It can occur when wool adsorbs large amounts of water, but not enough to feel 'wet'.

EXPLAIN THAT dry felting most commonly occurs in products such as:

- wool-filled pillows
- wool-filled mattresses.

EXPLAIN THAT dry felting occurs slowly.



EXPLAIN THAT the temperature and pH of wool also affect the rate of felting shrinkage.

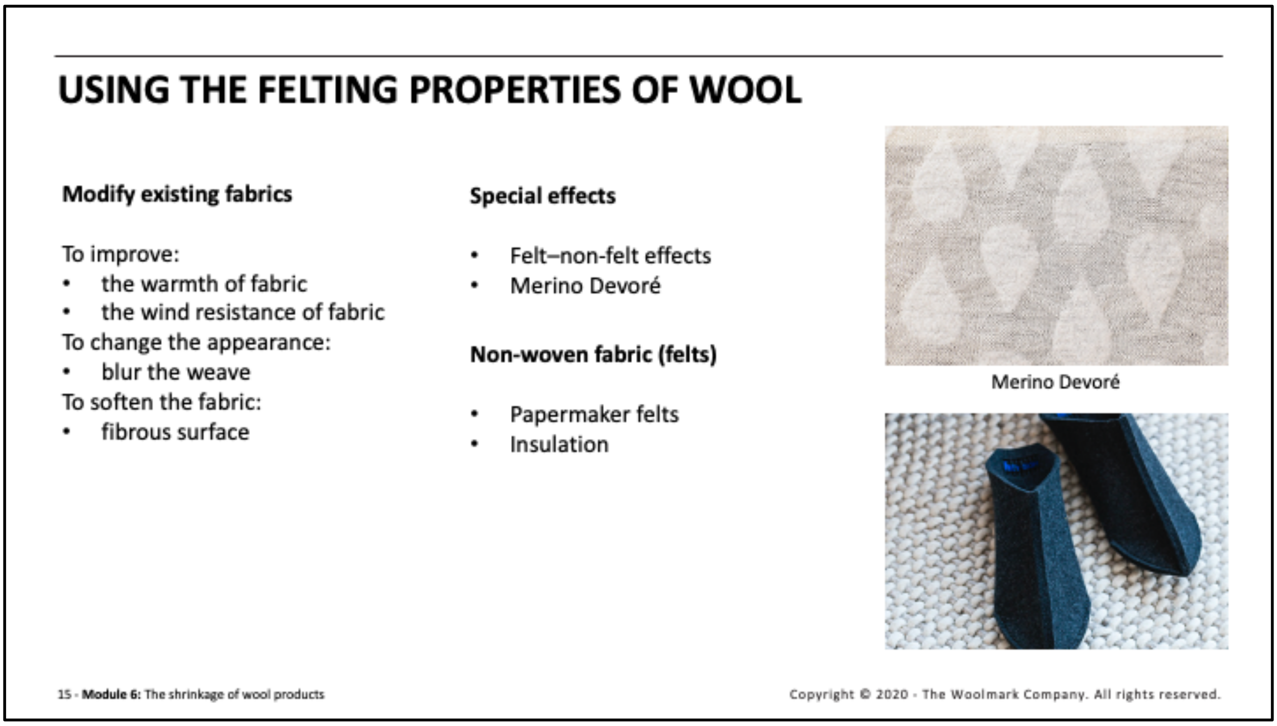
INDICATE THAT the hotter the water used to felt wool, the faster the felting.

EXPLAIN THAT wool also felts more rapidly in highly acid or highly alkaline solutions.

INDICATE THAT this probably is a result of the disruption of the salt links within the fibre and increased swelling of the endocuticle.

ASK *participants if they have any questions about the five key factors that affect felting shrinkage before you move on to discuss how the felting characteristics of wool can be used to develop novel products.*

ADDRESS *any questions in a timely manner.*



EXPLAIN THAT the felting shrinkage characteristics of wool and other animal fibres can be utilised to produce a range of novel products.

POINT OUT that the controlled felting of existing wool fabric will:

- increase fabric thickness, making the fabric warmer with better wind resistance
- change the appearance of a fabric, giving it a fuzzy surface, partially obscuring the weave. This can also make the fabric feel softer.
- change the geometry of the surface by completely obscuring the weave and making the surface of the fabric flatter. An example is billiard table cloth.

EXPLAIN THAT control of felting shrinkage to sections of wool fabrics or garments, allows the imposition of fashion affects including:

- three-dimensional effects
- Devoré effects without the need to dissolve the fibre (as shown on the slide).

EXPLAIN THAT if there is sufficient felting of the fibres in a fibre mass, the mass develops strength and cohesion. A fabric is formed without the need to spin yarn then knit or weave (as illustrated by the felted slippers on the slide).

EXPLAIN THAT if the fibres are felted as a flat sheet, a non-woven fabric also can be made.

PROVIDE THE example of papermaking felts as a product made by felting a sheet of wool fibre so the sheet develops adequate cohesive strength.

NOTE THAT non-woven fabrics are used in apparel and interior textiles.

***ASK** participants if they have any experience with felted wool products.*

***ACKNOWLEDGE** any responses appropriately before explaining that you will now discuss how wool can be treated to preventing felting shrinkage.*

***ASK** participants to list the two mechanisms of shrinkage in wool.*

***RECORD** correct responses below on the flipchart or whiteboard:*

- *relaxation shrinkage*
- *felting shrinkage.*

FELTED YARNS

Felted yarns can be produced directly from carded slivers or worsted rovings using the Periloc process.

Felting changes the structure and properties of the resulting yarn by:

- increasing the linear density (yarn count)
- increasing the yarn bulk
- increasing the abrasion resistance
- reducing fibre shedding in the final product.

https://www.woolcouturecompany.com/product/gigantic-felted-yarn/

16 - **Module 6:** The shrinkage of wool products

EXPLAIN THAT felted yarns can be created directly from carded slivers or worsted rovings using the Periloc process, developed by the International Wool Secretariat (IWS). Alternatively the same process may be applied to spun yarns to impart felted characteristics.

INDICATE THAT in this process, the sliver, roving or pre-spun yarn is wetted with water containing a detergent and passed through a plastic tube. The tube is compressed by a series of rollers, which provide the mechanical action required for felting to occur.

EXPLAIN THAT felting changes the structure and properties of the resulting yarn by:

- increasing the linear density (yarn count)
- increasing the yarn bulk
- increasing the abrasion resistance
- reducing fibre shedding in the final product.

NOTE THAT this felting process is most often applied to heavy-count woollen and semi-worsted spun yarns used in carpets and in craft knitting.

SHRINK RESISTANCE — FELT-RESIST TREATMENTS

Felt-resist treatment is required for machine washability of wool garments.

Wool can be:

- woven from felt-resist treated yarns
- treated in fabric form
- treated in garment form

Three methods are used for 'felt-resistance':

- degrading the cuticle cells
- a degradative pre-treatment followed by applying a polymer
- applying a polymer, which forms bonds between the fibres.

17 - **Module 6:** The shrinkage of wool products

REINFORCE THAT garments shrink during washing by two mechanisms:

- relaxation shrinkage
- felting shrinkage.

EXPLAIN THAT felt-resistance is essential to meet the increasing demand for machine-washable wool garments.

INDICATE THAT fabric and garments can be:

- produced from felt-resistant treated yarns, where the treatment was carried out when the wool fibre were still separated (as top or loose fibre). This is most common for knitted fabrics.
- treated in fabric form to impart felt resistance. This is most common for woven fabrics.

EXPLAIN THAT two methods are used to impart felt resistance to wool fibres in loose fibre or top form:

- degradation of the scales using oxidation
- an oxidative pre-treatment, followed by application of a polymer. This mechanism involves modifying the frictional properties of the fibre and 'scale masking'.

EXPLAIN THAT two methods are used to impart felt resistance to wool fabrics and garments.

- application of a polymer, which forms bonds between the fibres, preventing relative fibre movement
- an oxidative pre-treatment, followed by application of a polymer. The mechanism is a combination of scale degradation, scale masking and the formation of interfibre bonds.

INDICATE THAT you will now look at these processes in more depth.

DEGRADATION OF THE CUTICLE CELLS

Mechanism

- Cuticle cells (scales) damaged
  - Reduces directional friction effect (DFE)
  - Increases wet friction
- Damage to the fibre accompanies the felt-resist effect.
- Normally used to achieve only hand wash performance.

Chemical

- Oxidation with chlorine
- Oxidation with peroxides

Plasma

- Normally confined to the cuticle cells
- Damage to cortical cells limited
- Felt-resist effect limited

Enzymatic processes

- Protease used
- Risk of damaging the whole fibre
- Difficult to prevent weight loss in the fibre

18 - **Module 6:** The shrinkage of wool products

EXPLAIN THAT simple degradation of the cuticle cells (scales) has the following effects:

- Degradation reduces directional friction effect (DFE).
- Degradation increases wet friction between the fibres, which reduces their ability to move when subjected to mechanical action.

NOTE THAT the effect on the DFE of the fibre is thought to be the more important mechanism in imparting felt-resistance.

EXPLAIN THAT damage to the fibre accompanies the felt-resist effect, and includes:

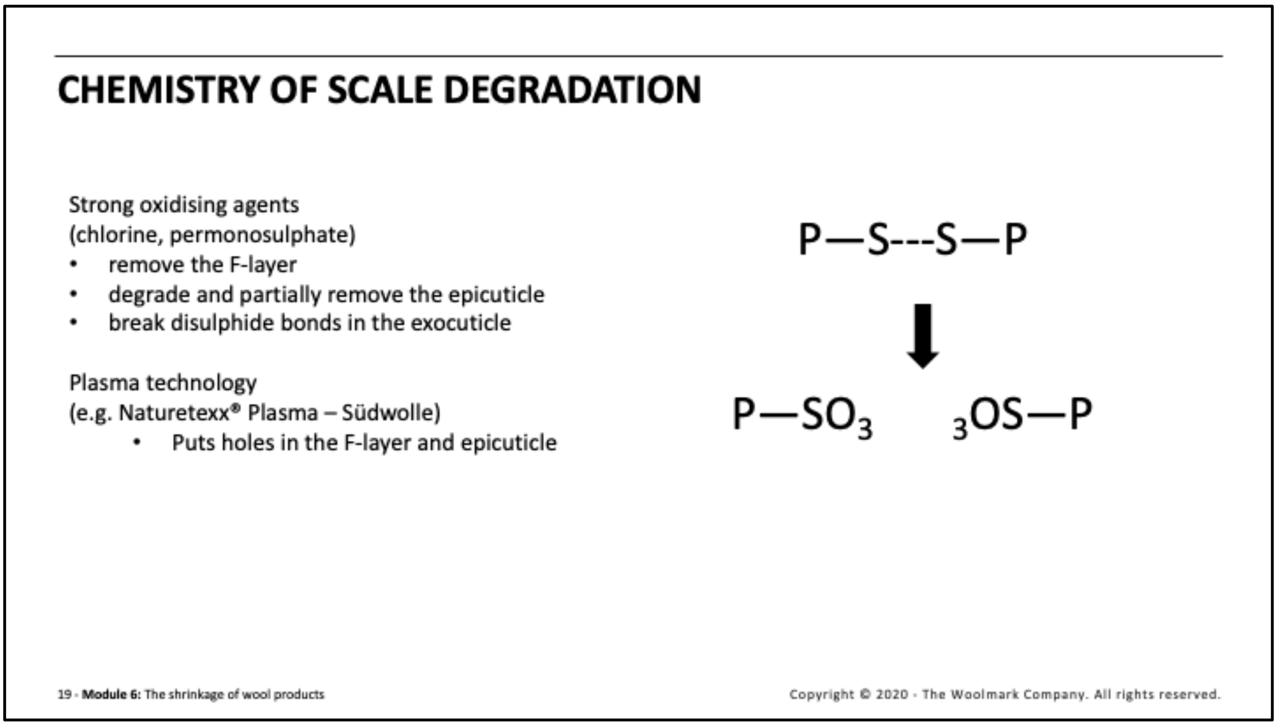
- loss of fibre strength
- change in dyeing behaviour.

INDICATE THAT processes that involve simple degradation to the cuticle cells are normally used to achieve hand wash performance only . Achieving high levels of felt resistance does too much damage to the rest of the fibre.

EXPLAIN THAT it is difficult to limit the damage to the fibre surface when treating wool to prevent felting shrinkage.

BRIEFLY OUTLINE the following processes used to degrade the fibre surface:

- chemical processes
  - oxidation with chlorine
  - oxidation with peroxides
- plasma treatment
  - normally confined to the cuticle cells
  - damage to cortical cells limited
  - felt resist effect limited
- enzymatic processes
  - protease used
  - difficult to prevent damage to the whole fibre
  - there can be significant weight loss in the fibre.



EXPLAIN THAT the chemistry of felt resistance can be complex.

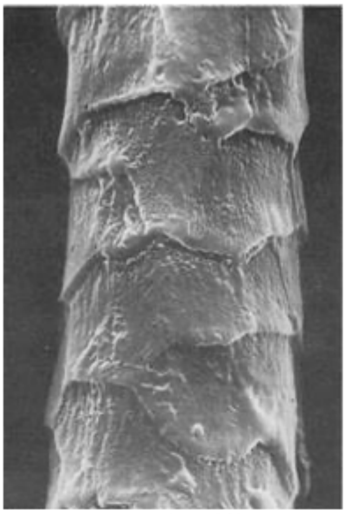
INDICATE THAT strong oxidising agents (e.g. chlorine and permonosulphate):

- remove the F-layer by breaking the bond between the lipid layer and the protein macromolecules (i.e. increasing fibre friction)
- degrade and partially remove the epicuticle (i.e. no Allworden reaction in treated fibre)
- break disulphide bonds in the exocuticle A-layer. (**REINFORCE THAT** this layer is then more easily swollen by water and the fibre develops a softer jelly-like surface in water. A highly anionic surface is created with P-SO_3 groups on surface — as indicated on the slide).

EXPLAIN THAT plasma technology is an alternative approach to chemical degradation that creates holes in the F-layer and epicuticle.

INDICATE THAT an example of a recent commercial plasma process is Naturetexx® Plasma – Südwolle (http://www.naturetexxplasma.com/en/#c5).

DEGRADATION OF CUTICLE + POLYMER TREATMENTS



Hercosett-treated wool fibre

Commonly used for treatment of

- top
- knitted fabric
- knitted garments
- rarely used on woven fabrics

Mechanism

- **The treatment** degrades the cuticle cells reducing the directional friction effect.
- **The polymer** masks the cuticle cells further reducing the directional friction effect

Degradative processes commercially used

- oxidation (peroxides or chlorine)
- plasma

20 - **Module 6:** The shrinkage of wool products

REMIND participants that another option to treat wool fibres to reduce felting shrinkage is to degrade the cuticle cells and then apply a scale-masking polymer to the fibre surface.

EXPLAIN THAT an oxidation is carried out to impart a small amount of damage the cuticle cells on the fibre . This produces:

- a small reduction in the directional friction effect
- improved adhesion between the polymer and the fibre.

INDICATE THAT the most common oxidants used in this process are chlorine or permonosulphate salts (PMS).

EXPLAIN THAT a polymer is then applied to the surface of the wool, which:

- masks the cuticle cells
- results in a large reduction in the directional friction effect.

EXPLAIN THAT the most common polymer applied to wool fibres to impart felt resistance is Hercosett — a water-soluble epichlorhydrin-functional polyamide.

OUTLINE THAT during the process, the polymer crosslinks (cures) in a heat treatment to prevent it washing off the wool. The polymer swells when wet to mask the scales.

EXPLAIN THAT other proprietary products can also be used.

FELT-RESIST PROCESSING OF WOOL FIBRE AS TOP

Pre-treatment using chlorine or *PMS

Neutralisation and extraction

Resin application

Softener application

*PMS = Permonosulphuric acid (or salt)

21 - **Module 6:** The shrinkage of wool products

PLAY *the two-minute video, which outlines the stages of the felt-resist process of wool in fibre form as top.*

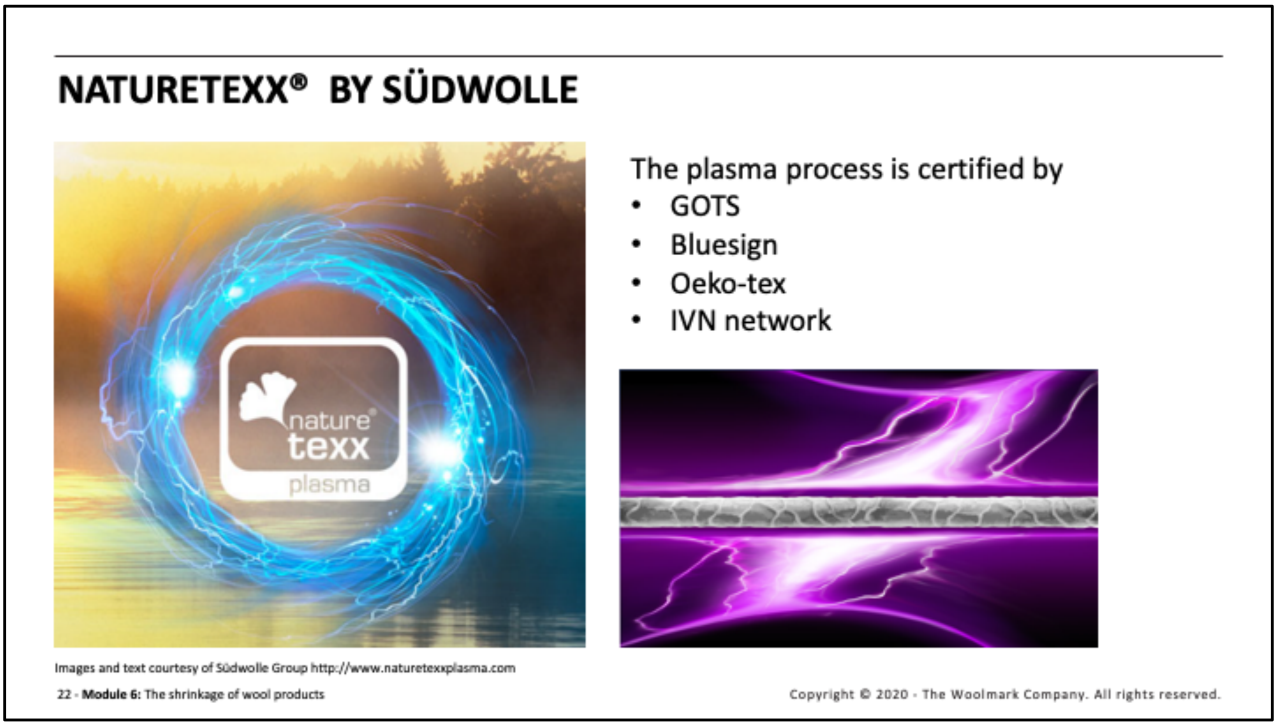
EXPLAIN THE process as the video plays

- oxidation with chlorine or another oxidising agent to damage the cuticle cells
- neutralisation with sodium sulphite or sodium bisulphite to remove any remaining oxidant, which could continue to damage the wool
- alkaline rinsing to remove any water-soluble protein formed by the extensive oxidation of disulphide crosslinks in the part of the exocuticle remaining on the fibre
- polymer application — the polymer (usually Hercosett) is positively charged and exhausts onto the negatively-charged fibre surface created by the oxidation
- drying and curing the treated top to render the polymer insoluble
- applying a softener from aqueous solution to restore the handle of the fibres
- final drying of the tops.

EXPLAIN THAT in some instances the resin and softener can be applied in the same process.

ASK *participants if they have any questions about what they have seen on the video.*

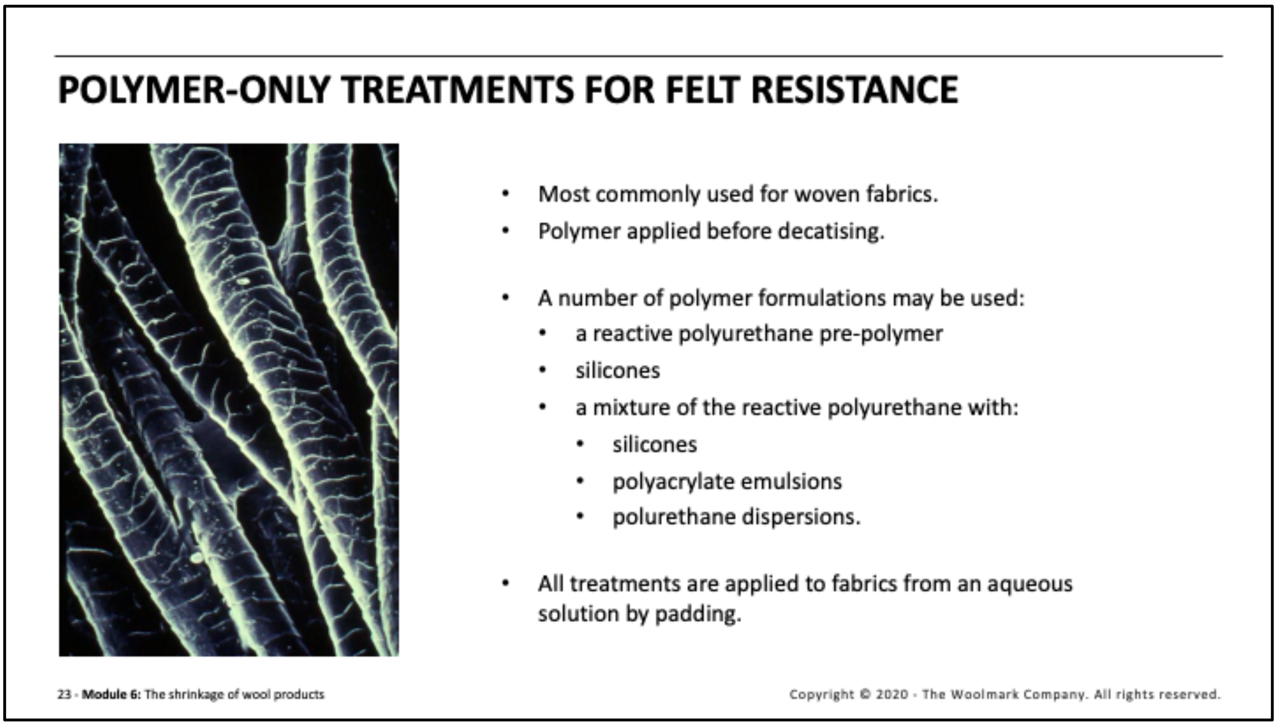
ADDRESS *any questions in a timely manner.*



EXPLAIN THAT the plasma-based process used by the Südwolle Group is considered to be more environmentally friendly than processes that use chlorine or strong oxidants.

It is certified by the following eco-labels:

- Global Organic Textile Standard
- Bluesign
- Oeko-tex
- IVN network.



EXPLAIN THAT polymer-only treatments are the most commonly-used approach to impart felt resistance in woven wool fabrics. The treatment is applied before decatising (during fabric finishing).

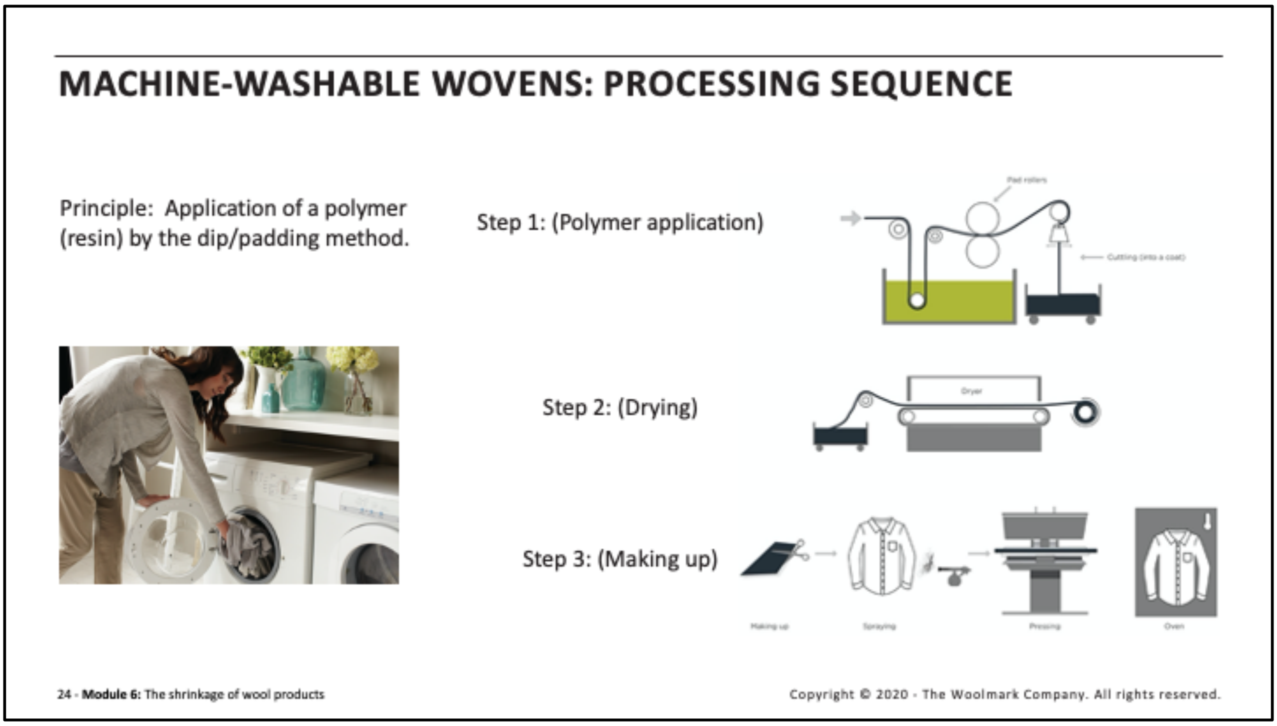
The polymer is applied from aqueous solution or emulsion. It is crosslinked (cured) after application to prevent removal.

EXPLAIN THAT the polymer prevents felting by preventing relative motion of the fibres in the yarns (and thus felting) when mechanical action is applied.

INDICATE THAT a number of polymer formulations can be used, including:

- a reactive polyurethane pre-polymer (water soluble)
- silicones
- a mixture of the water-soluble reactive polyurethane with:
    - silicones
    - polyacrylate emulsions
    - polyurethane dispersions.

NOTE: This process cannot be used to treat wool in fibre form (loose wool or top) — the interfibre bonds will be broken in subsequent processes. It can only be used when the fibre is in fabric form and is applied from an aqueous solution by padding.



EXPLAIN THAT polymer-based felt-resist processes are applied by 'padding' in an aqueous solution of emulsion as shown in the steps on the slide.

INDICATE THAT following the application process, the wet fabric is dried and heated to cure (crosslink) the polymer.

NOTE: This process is normally used on woven fabrics, but can also be applied to a limited number of knitted fabrics.

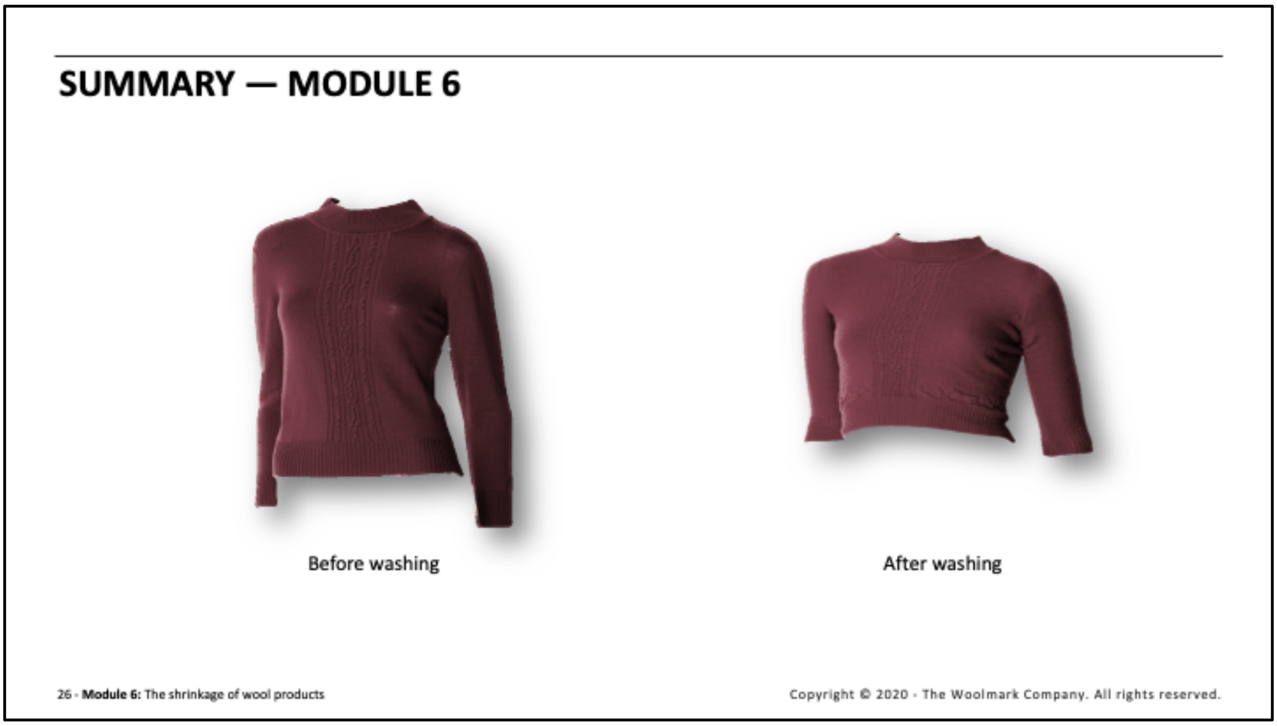
EXPLAIN THAT you will now play a short video, which shows fabric being:

- dipped in to an aqueous solution of the polymer
- squeezed to remove an excess liquid (the squeezing of the fabric ensures the correct amount of the polymer on the fabric and its even application)
- dried — the polymer forms bonds between adjacent fibres preventing their relative motion.)
- cured — during curing the polymer is crosslinked to render it insoluble.

EXPLAIN THAT this process is normally only applied to fabric in open width (prior to being formed into a garment).

ASK *participants if they have any questions about what they have seen on the video.*

ADDRESS *any questions in a timely manner.*



SUMMARISE this module by reinforcing the key elements of the two mechanisms of shrinkage dimensional change in wool fabrics:

Relaxation shrinkage:

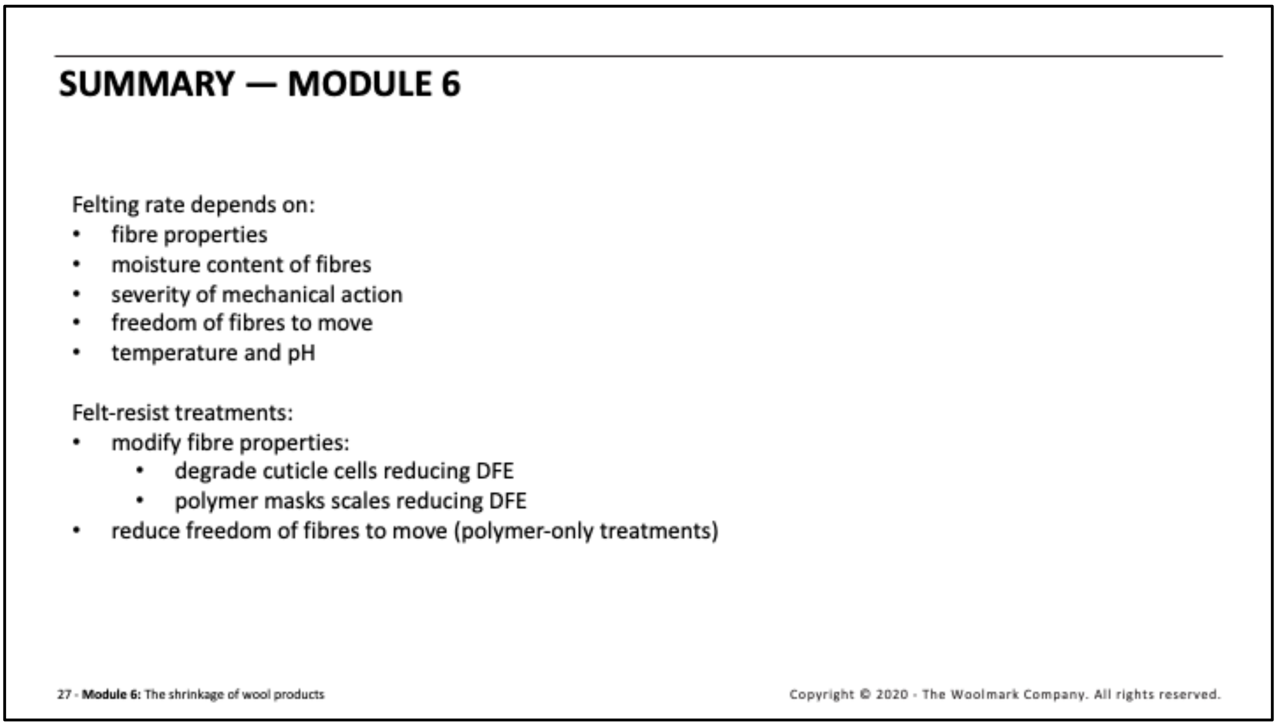
- associated with cohesive setting of the fibre and is reversible

Felting shrinkage:

- is associated with the unique frictional properties of the fibre
- is caused by the directional friction effect
- involves a ratchet mechanism
- is seen as a matting of the fibres.
- requires mechanical action on the fibres and adequate moisture in the fibres (normally wet)
- is not reversible.

REMIND participants that felting shrinkage of wool can be used to advantage to:

- modify existing fabric
- create novel fashion effects
- create non-woven fabrics
- create felted yarns.



REINFORCE THAT felting rate depends on:

- fibre properties
- moisture content of fibres
- severity of mechanical action
- freedom of fibres to move within the structure
- temperature and pH.

REVIEW THE two main mechanisms of employing felt-resist treatments:

- reducing the directional friction effect (DFE)
- restricting relative movement of the fibres.

RE-CAP THAT three methods of felt-resist treatment:

- damaging the cuticle on the fibre, which
    - reduces the DFE and to a lesser extent restricts fibre movement
    - can be used on wool at all stages of processing
- damaging the cuticle and adding a scale-masking polymer
    - reduces the DFE of the fibre by masking the scales
    - can be used on wool at all stages of processing
- applying a polymer (only)
    - restricts fibre movement
    - limited to use on yarns, fabrics and garments.

***ASK** participants if they have any further questions about the content covered in this module.*

***ALLOW** time for questions and discussion before proceeding to the final slide and closing the lecture.*

INFORM participants of the time and location for the final lecture in the *Wool fibre science* unit — *Module 7 The benefits of wool* — and ensure they read through the relevant notes in their Participant Guides before attending the lecture.

ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in today's lecture.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

BEFORE participants leave ensure you have collected all fibre samples distributed during the lecture.

THE WOOLMARK COMPANY

MODULE 7

THE BENEFITS OF WOOL

RESOURCES — MODULE 7: THE BENEFITS OF WOOL

Contained in the *Wool fibre science* Demonstration kit you will find the following resources for use as you deliver **Module 7: The benefits of wool** you will need to source:

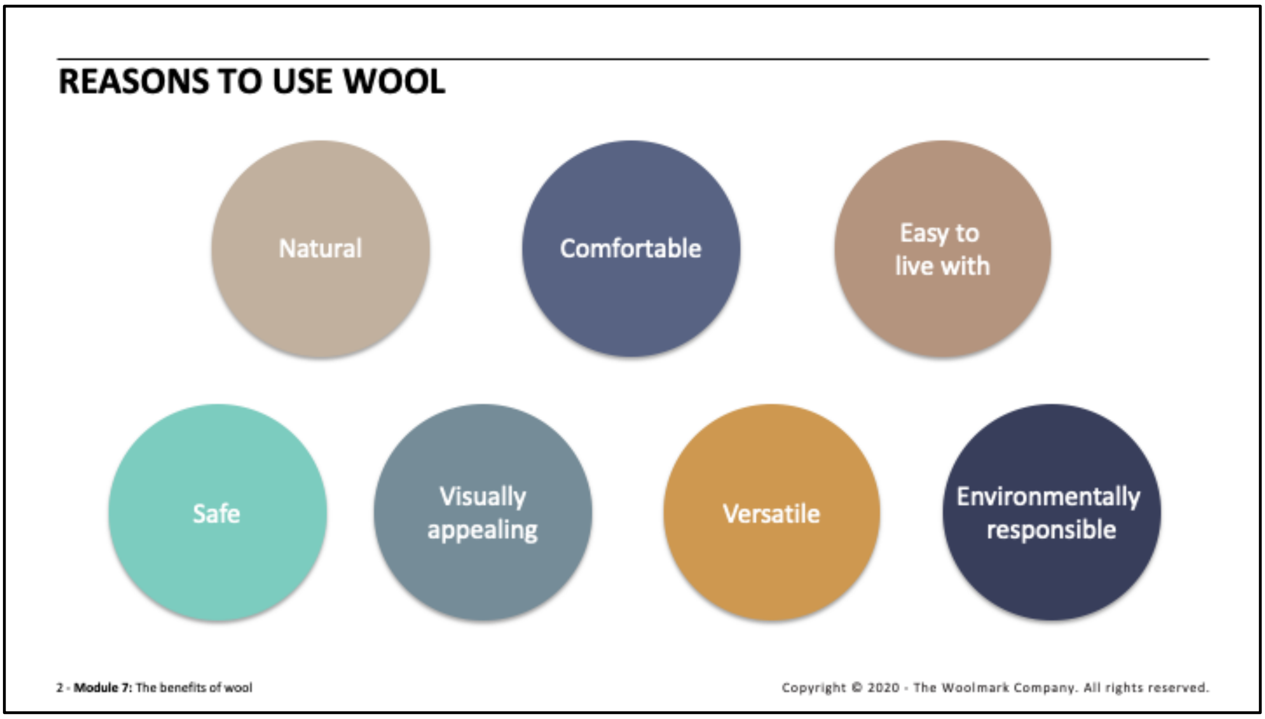
- TWC knitting needles (fine and large).

Facilitator:

- cotton t-shirt
- wool t-shirt
- wool shirt
- wool sock
- cotton sock
- eye dropper.

WELCOME participants to Module 7 of the Woolmark Wool Science, Technology and Design Education Program *Wool fibre science — The benefits of wool*.

REMIND students this is the final in this course.



REINFORCE THAT, as has been demonstrated during this course, wool is a complex fibre.

EXPLAIN THAT the structure, physics and chemistry of the wool fibre translate into a range of properties and benefits, which deliver sound reasons for choosing wool across a wide variety of applications:

INDICATE THAT these reasons include:

- Wool is natural — wool is a natural fibre and is a renewable resource.
- Wool is comfortable — comfort is derived from a combination of softness, moisture management and temperature control
- Wool is easy to live with — wool is durable, has soil and stain resistance properties, may be laundered easily and is ideal for sensitive skin
- Wool is safe — wool has fire resistant and UV absorption properties
- Wool is visually appealing — the structure and physics of the fibre impart qualities that offer a superior handle and drape. Additionally wool has good wrinkle recovery.
- Wool is versatile — wool's inherent properties mean it is the ideal fibre across a broad range of applications
- Wool is environmentally responsible — wool's inherent properties also contribute to its environmental footprint. In addition to being a renewable and biodegradable natural fibre, wool is also recyclable. Reclaimed fibre is used in the creation of a wide range of new wool products, extending the useful life of wool.

EXPLAIN THAT this module will explore the properties and benefits associated with wool that would persuade consumers to use it and relate these advantages to the fibre structure, physics and chemistry of wool.

INFORM participants that by the end of this module they will be able to:

- describe the key properties and benefits of wool as a fibre
- relate these properties to the fibre's structure, physics and chemistry
- explain the benefits from choosing wool across a range of applications.

RESOURCES REQUIRED FOR THIS MODULE

- *TWC knitting needles (fine and large).*
- *cotton t-shirt*
- *wool t-shirt*
- *wool shirt*
- *wool sock*
- *cotton sock*
- *eye dropper.*

***PLAY** the short video Wool runs on grass and ask students to note the natural resources used to produce wool.*

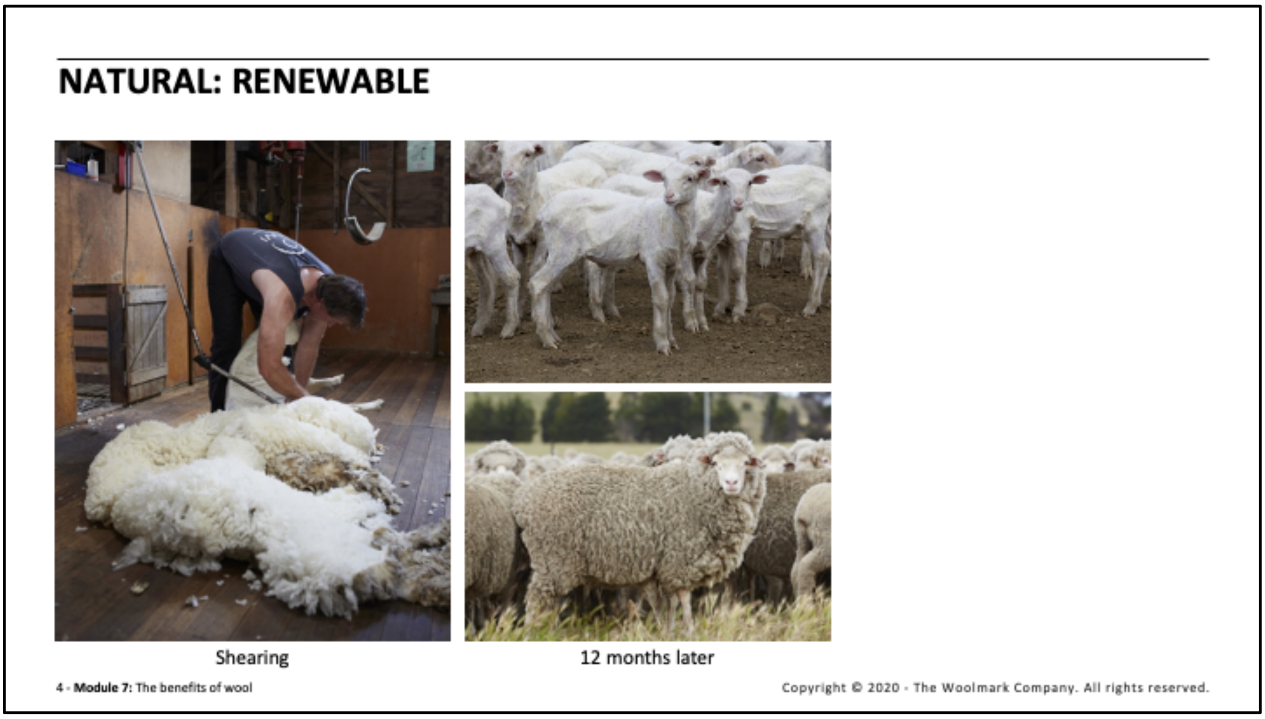
***ASK** participants to describe three natural resources sheep require to produce wool.*

***ACKNOWLEDGE** participants' responses and list 'air', 'water' and 'grass' on the flipchart or whiteboard as participants respond or at the end of the discussion if they are not mentioned.*

EXPLAIN THAT one major reason people choose wool is because it is a natural resource.

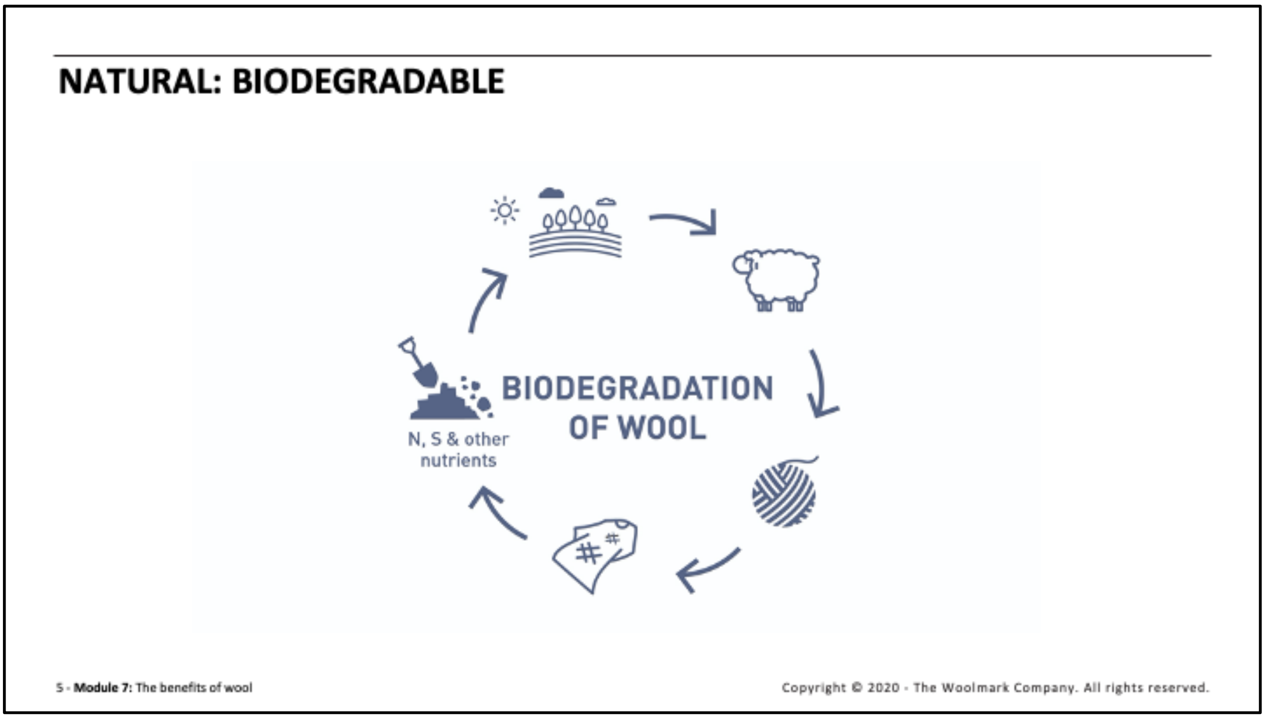
REINFORCE that by consuming a combination of water, grass and sunshine, sheep produce wool — a completely natural fibre.

POINT OUT participants can access the video in their own time using the link provided in their *Participant Guide*: https://www.youtube.com/watch?v=uD19PM7S2S8



EXPLAIN THAT in addition to being a natural resource, wool is a completely renewable resource. Each year the wool fleece is carefully removed, without harming the animal, during shearing.

During the next 12 months the sheep grows a new fleece...the process is repeated again and again and again.



EXPLAIN THAT because wool is composed of protein (keratin), microbes within the soil digest the fibre and return nutrients to the soil. Synthetic fibres, on the other hand, can be extremely slow to degrade and significantly contribute to the world's overflowing landfills. In landfills wool degrades rapidly with no long-term damage to the environment

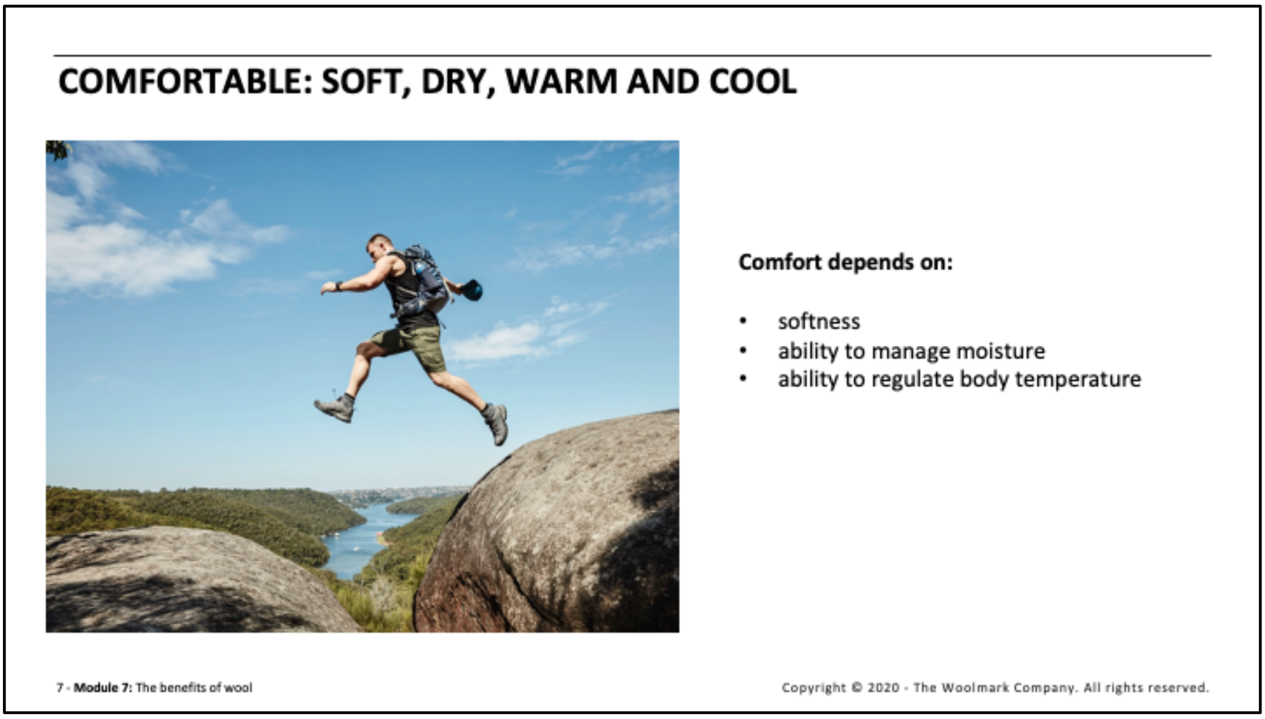
EXPLAIN THAT if wool is kept warm and moist or buried in soil, bacteria and fungal growths develop, which produce enzymes that digest wool.

On the other hand, thanks to the unique chemical structure of keratin and wool's tough, water-repellent outer layer, clean and dry wool fibres do not readily degrade in normal use and storage. This allows wool products to be resilient and long-lasting in normal conditions.

EXPLAIN THAT wool can be composted with other organic material to create a type of fertiliser, rich in nutrients, which can be used to improve pasture for animals.

POINT OUT that trials run in New Zealand demonstrated that wool decomposed in soil in a matter of weeks, whereas the synthetic fibres (in this case an acrylic) remained for months or years.

Similar trials on a smaller scale were carried out at the property of the Prince of Wales in the United Kingdom. Again the wool decomposed, where the synthetic garment did not.



***HAND OUT** samples of the following wool garments for participants to feel during the next few slides covering 'the comfort of wool':*
- *Merino wool t-shirt*
- *Merino wool beanie (TWC)*
- *Merino wool socks*

***ASK** participants to describe how these wool products feel.*

***RECORD** responses on the flipchart or whiteboard.*

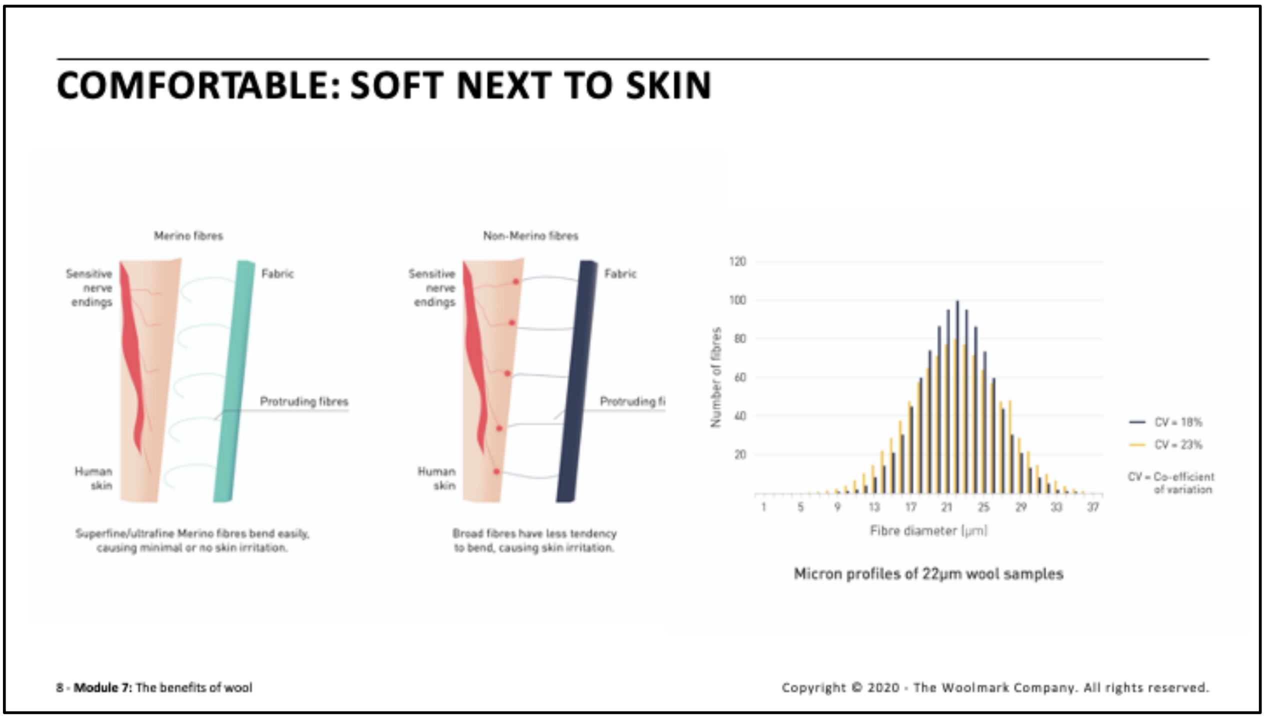
EXPLAIN THAT wool's comfort can be explained by its
- softness,
- ability to manage moisture
- ability regulate your body temperature.

POINT OUT that when people are involved in activity, they have little control over environmental conditions, but they do have a choice of clothing.

INDICATE THAT the level of activity and the environment in which the activity is undertaken dictate the properties the clothing must offer for optimal comfort.

The environment may be hot or cold, wet or dry and the level of activity can range from gentle to strenuous.

EXPLAIN THAT the inherent properties of wool mean it can:
- feel soft next to your skin
- help keep you cooler when it is hot
- keep you warmer when it is cold
- keep you dry when the environment is moist and when you perspire.



EXPLAIN THAT softness, especially next to the skin, is directly related to the fineness (diameter) of the wool fibre. Broad fibres, which are ≥30µm, can trigger nerve endings in the skin because they are less able to bend as covered in *Module 3 — Wool fibre science*. This can make the wearer feel 'itchy'. In contrast, finer fibres bend more easily and exert less pressure on the nerves at the skin surface (as shown in the diagram on the slide) making them feel softer.

EXPLAIN THAT the fine fibres of Merino wool bend easily, which makes it feel soft to touch and to wear. Softness can be guaranteed by paying attention to the spread of fibre diameters within a blend.

DEMONSTRATION — BENDING RIGIDITY

- *Using one thin needle and one thick needle, holding one needle in hand, place the ends of the needles on a flat surface (e.g. table or bench) and apply pressure to show the 'bendability' according to the thickness of each needle.*
- *Indicate to participants that the needles represent the impact of fibre diameter on skin comfort due to 'bendability'.*

ASK *participants which needle would apply less pressure (and hence be more comfortable) next to the skin.*

ACKNOWLEDGE RESPONSES *and reinforce the concept is demonstrated in the illustration on the slide.*

EXPLAIN THAT the graph on the slide illustrates how two samples of wool can have the same mean (average) fibre diameter, but a different number of coarse fibres within the sample.

NOTE: The graph shows the distribution of fibres within two samples of wool, each with a mean fibre diameter of 22µm. The 'green' wool will make softer products than the 'red' wool.

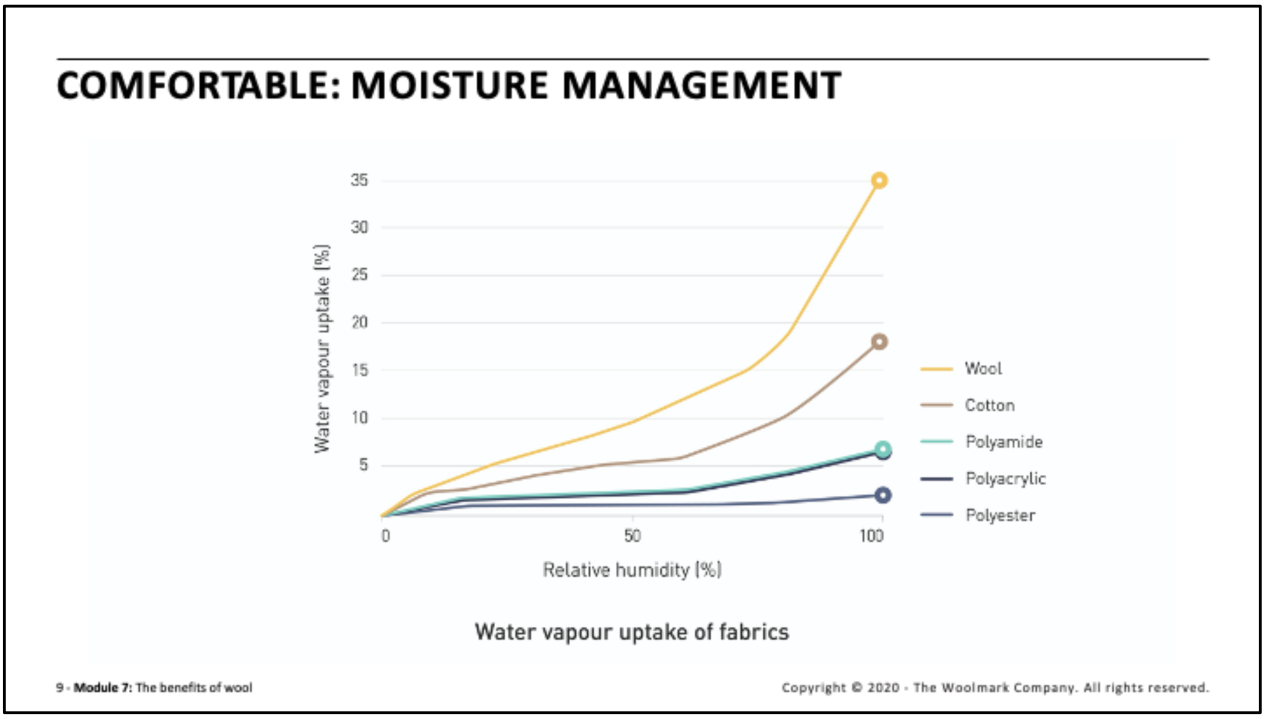
EXPLAIN THAT the coefficient of variation (CV) is a measure of the 'spread' of micron values within a blend (as illustrated in the graph). The larger the CV value:

- the greater the variation in the diameter of the wool fibres within the sample
- the greater the number of broad fibres (>30um) contained within the sample

EXPLAIN THAT a wool sample with high CV (e.g. 23% as illustrated in the graph) will feel less soft when compared to a sample with a low CV value (e.g. 18% as illustrated in the graph).

ASK *participants if they have any questions about concepts of fibre diameter in relation to 'softness' before you move on to discuss the concept of moisture management in relation to comfort.*

ADDRESS *any questions in a timely manner.*



EXPLAIN THAT there are two different types of moisture to manage:

- water vapour that occurs due to humidity in the air and can be high next to the skin due to insensible perspiration
- liquid water that occurs when it rains or when you sweat (sensible perspiration).

EXPLAIN THAT wool is good at controlling moisture vapour and liquid water.

REFER to the graph on the slide, which illustrates that most textiles can absorb water vapour — some more than others.

EXPLAIN THAT it shows that wool is much better at absorbing water vapour, compared with other fabrics, as the humidity in the air increases. The reason wool can absorb water better than other materials is a result of all the polar groups in the fibre which can bond with the water molecules. Wool is 'hygroscopic' .

EXPLAIN THAT in contrast, some synthetic fibres, rely on trapping the water in tiny pockets. As a result, synthetic fibres become 'wetter' faster than wool.

POINT OUT that wool can absorb up to a third of its own weight of moisture vapour at high humidity, without feeling wet.

EXPLAIN THAT if you run and start to sweat, the wool next to your skin will keep you dry by firstly absorbing the moisture vapour. When sweating starts, the texture of the wool knit will keep the fabric off the skin, so it clings less.

EXPLAIN THAT controlled tests by the CSIRO in Australia have shown that wearers exercising in Merino sports shirts feel less clammy than in corresponding polyester garments.

POINT OUT although wool can absorb moisture vapour, it repels liquid water. The F-layer is hydrophobic so the scales on the outside of the fibre cause liquid to roll off the fabric surface.

DEMONSTRATION — MOISTURE MANAGEMENT

Resources required

- *Wool sock*
- *Cotton sock*
- *Eyedropper containing water*

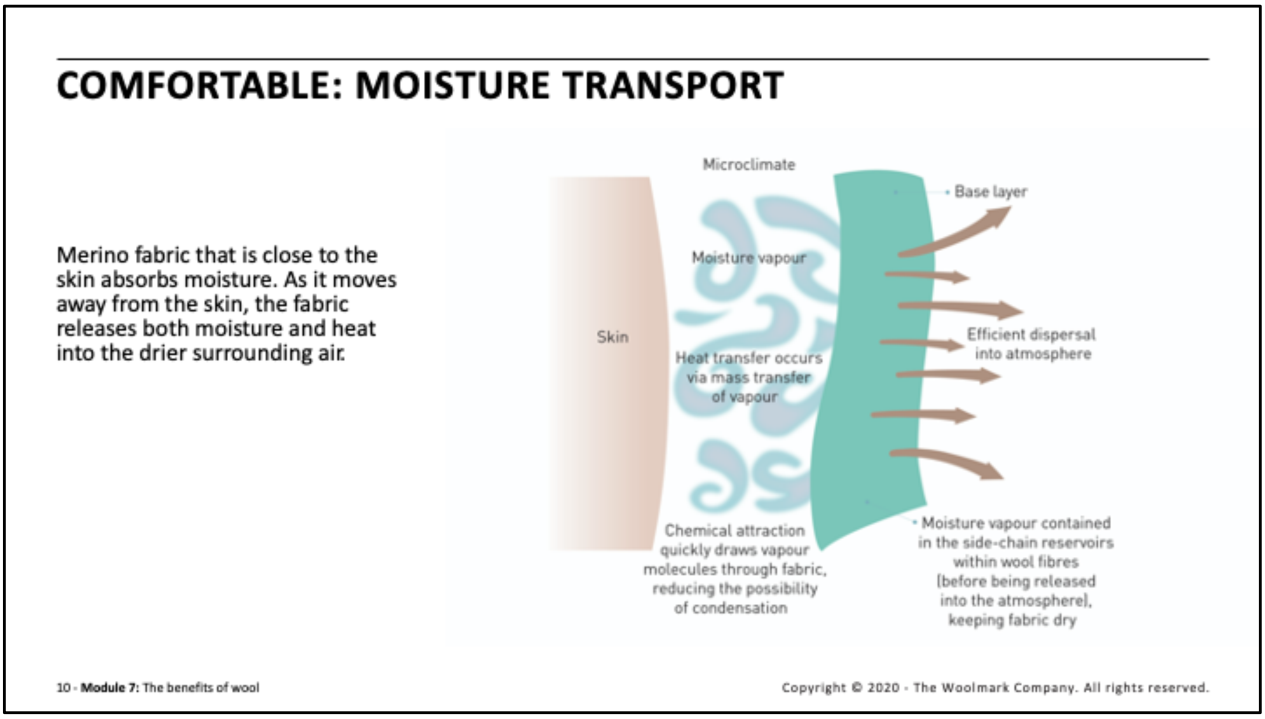
PROVIDE TWO *volunteers with a sock to place one of their hands (one cotton; one wool)..*

ASK *each volunteer open their hands and hold then in a horizontal position in front of their body.*

PLACE *a few drops of water on each sock and ask participants to observe what happens to the water.*

NOTE: *The cotton sock will quickly absorb the water and the water on the wool sock will remain as a drop of water sitting on top of the fibre.*

ASK *the participant with the cotton sock to mop up the water from the wool sock using their cotton sock before returning to their seats.*



EXPLAIN THAT wool's insulation properties, trapping air in the natural crimp of the fibres, help keep you warm when it's cold. In terms of thermal conductivity, wool is not really that different from other fabrics, such as cotton or polyester. The main reason why wool is better at controlling temperature is how it manages moisture.

When it is hot, wool manages moisture to keep you cooler.

REFER to the diagram on the slide, which illustrates how water is transported through fabric and away from the skin into the drier air.

EXPLAIN THAT when you exercise and start to sweat, the wool next to your skin automatically absorbs the vapour transporting it, and the heat associated with it, away from your skin, keeping you dry and comfortable. This movement of moisture away from your skin not only helps to keep you dry, it also helps keep you cool.

EXPLAIN THAT controlled tests by the CSIRO in Australia found that Merino fabric transports 27% more vapour away from the body than polyester fabric of identical construction.

REINFORCE THAT when it is cold, wool is a great insulator.

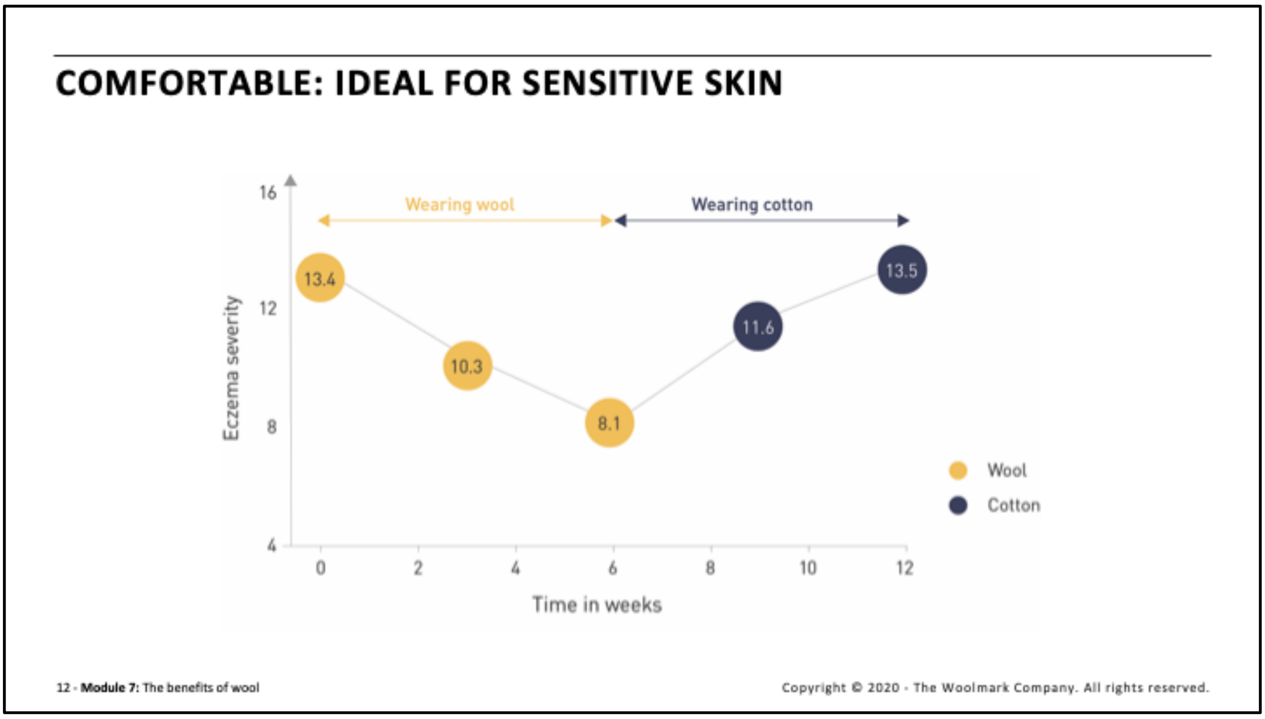
EXPLAIN THAT the crimp in the wool fibres makes them stand apart from each other, trapping air between the fibres and slowing down the rate of heat transfer. Still air is one of the best natural insulators and the ability to trap still air in the crimps means wool can help insulate against heat and cold.

REMIND participants that, as discussed in *Module 4: The chemistry of the wool fibre,* even as wool chemically bonds with water molecules it generates heat and helps keep the body warm, not cold and clammy.

REINFORCE THAT wool keeps you warm or cool depending on conditions. This apparent conflict (coolness v warmth) is possible because wool fibres can be made into different types of fabrics. In hot conditions we wear thin wool fabrics, which trap little or no air but adsorb and transport moisture well. In cold conditions we wear thicker bulky wool fabrics, which trap insulating air pockets affording good insulation while still controlling humidity.

ASK *participants if they have any questions about concepts moisture management and temperature regulation before you move on to discuss the final element related to comfort.*

ADDRESS *any questions in a timely manner.*



EXPLAIN THAT recently published research has demonstrated that wearing superfine Merino wool next to the skin is therapeutic for eczema sufferers. This adds to a growing number of research findings supporting the health and wellbeing benefits of superfine Merino wool.

OUTLINE that eczema, or atopic dermatitis, is an allergic condition where the skin becomes dry, leading to cracking, bacterial infection, redness and itching. It affects around 30% of children and its prevalence varies geographically. The most common treatments currently include the regular application of moisturisers and topical steroids to reduce inflammation, as well as antibiotics to address infection.

INDICATE THAT eczema sufferers have especially sensitive skin and an Australian study at the Murdoch Children's Research Institute has shown that wool garments made from soft and breathable superfine Merino wool were well tolerated by participants and reduced their eczema symptoms (NB: the garments must have a mean fibre diameter less than or equal to 17.5 micron).

The study, led by Associate Professor John Su, showed that superfine Merino wool clothing reduced the severity of paediatric mild-moderate atopic dermatitis as compared to cotton clothing.

REFER to the graph on the slide, which shows the reduction in eczema symptoms when wearing wool and the increase in symptoms when resuming cotton clothing.

The study concluded that traditional management guidelines should be modified to include superfine Merino wool as a recommended clothing choice in childhood atopic dermatitis.

INDICATE that interested participants can find more information on this research by following the link in their *Participant Guide*: https://www.woolmark.com/globalassets/woolmark/resources/fact-sheets/benefits/wool-is-good-for-skin.pdf/ or by watching the following YouTube clip https://www.youtube.com/watch?v=haJoNCceFgA&feature=youtu.be

The research paper mentioned can be found at: https://www.mcri.edu.au/sites/default/files/media/sudessinewoolonlinebjdarticle.pdf

EXPLAIN THAT wool is easy to live with for a number of reasons:

- Wool is durable.
- Wool is odour resistant.
- Wool is ideal for sensitive skin.
- Wool is soil and stain repellent.
- Wool can be machine washable.

EXPLAIN THAT in terms of its durability, although wool is not as strong as some other fibres, it can stretch further than other fibres, absorbing energy, before it breaks.

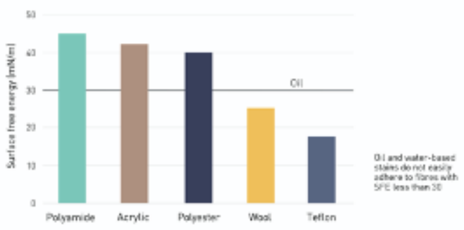
REFER TO the slide as you explain that the top graph shows the tenacity of wool fibre compared with other types of fibres. Providing that the yarn twists and fabric densities are sensible, wool's low relative tenacity (strength) is not normally an issue except in very lightweight woollen-spun products.

EXPLAIN THAT wool is more flexible and elastic than other fibres as illustrated by the second graph on the slide, which shows that the breaking extension of wool compared with other fibres. This means wool fibre can stretch, absorbing energy, much further than other fibres before it breaks. As the fibre extend the a-helices in the crystalline regions (microfibrils) extend, allowing the fibre to extend a long way (up to 30% without damage) before the fibre is overstretched and it ruptures.

POINT OUT that although fibre tenacity might be a weakness of wool, this is countered by its elasticity and flexibility, which make it resilient to wear. Because wool is both elastic and flexible (up to 20,000 times) it can absorb sudden stresses without breaking. As a consequence, it lasts a long time.

EASY TO LIVE WITH: SOIL AND STAIN REPELLENT

- Surface free energy: water = 72, cotton = 200
- Wool has a lower surface energy than many other fibres.
- Since most stains are water or liquid-based, wool is naturally stain-resistant.



Surface free energy of various fibre types

Water-repellent surface

23 - **Module 7:** The benefits of wool

EXPLAIN THAT another 'easy-to-live-with' feature of wool is its ability to repel soil and liquid-based stains.

REFER TO the graph on the slide, which shows the surface free energy of different materials. The surface free energy is a measure of the activity of the surface molecules. If the surface molecules are very active (the surface free energy is high), it is easy for other substances to adhere to them (i.e. high propensity for soiling).

EXPLAIN THAT if a substance has a high surface energy it can be more easily wet by water (water has a surface energy of 72).

REMIND participants that wool fibres have a hydrophobic surface as a result of the presence of the F-layer. It has a surface energy lower than water (about 25), and so is below the value at which wetting readily occurs, making the surface of wool water-repellent (as described in earlier topics).

EXPLAIN THAT because most stains are water-based, they are not readily absorbed by the wool fibre and are easily removed.

ASK participants to reflect on the demonstration with the wool and cotton socks and relate this to the concept of water-based-stain resistance.

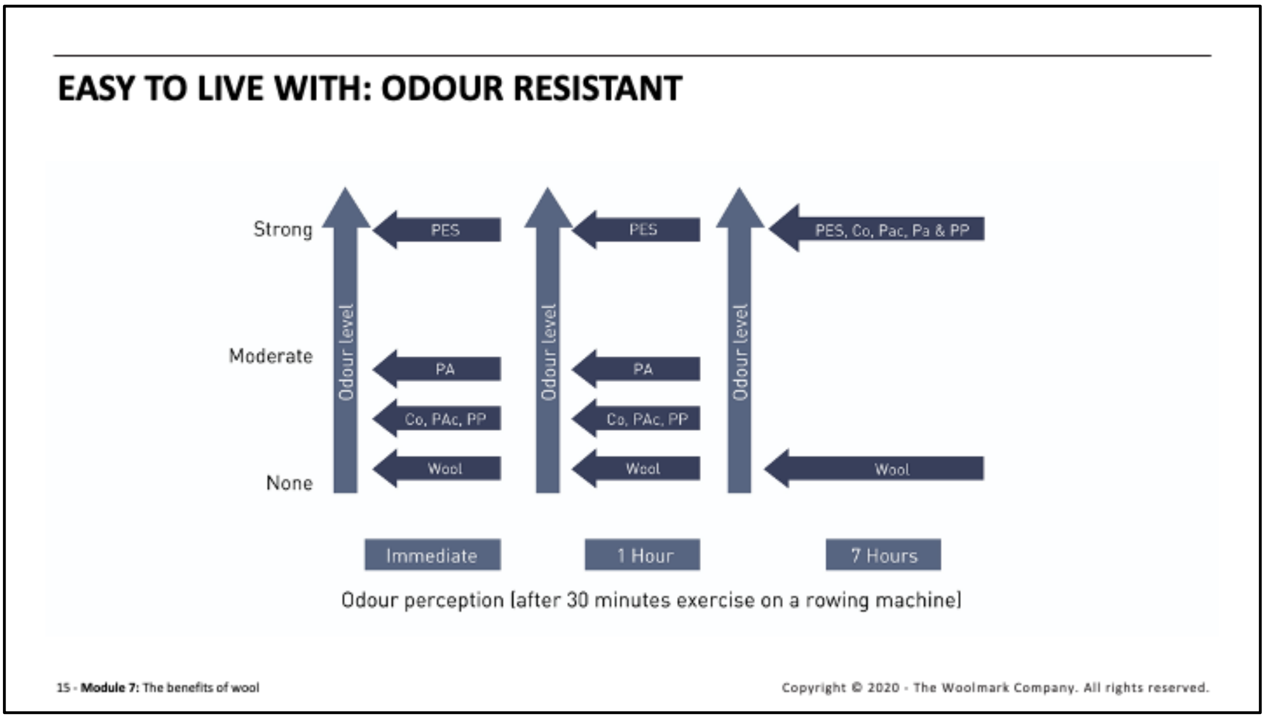
NOTE THAT wool's natural stain-resistance means wool requires less laundering than other materials.

EXPLAIN THAT the F-layer on the fibre ensures that wool even has some oil-repellency so some oil-based stains can be resisted.

INDICATE finally that wool's ability to absorb moisture and impart a low build-up of static electricity means it does not attract lint and dust from the air.

ASK *participants if they have any questions about the concepts of durability and stain repellence before you move on to discuss odour resistance.*

ADDRESS *any questions in a timely manner.*



EXPLAIN THAT wool adsorbs a range of odorous gases including: formaldehyde, hydrogen sulphide and other sulphurous gases.

INDICATE THAT one of the consequences of this process is that wool manages human odours that develop during exercise leaving the wearer smelling fresher after exercise than if they were wearing an alternative fibre.

EXPLAIN THAT there are two ways wool reduces odour during high levels of activity:

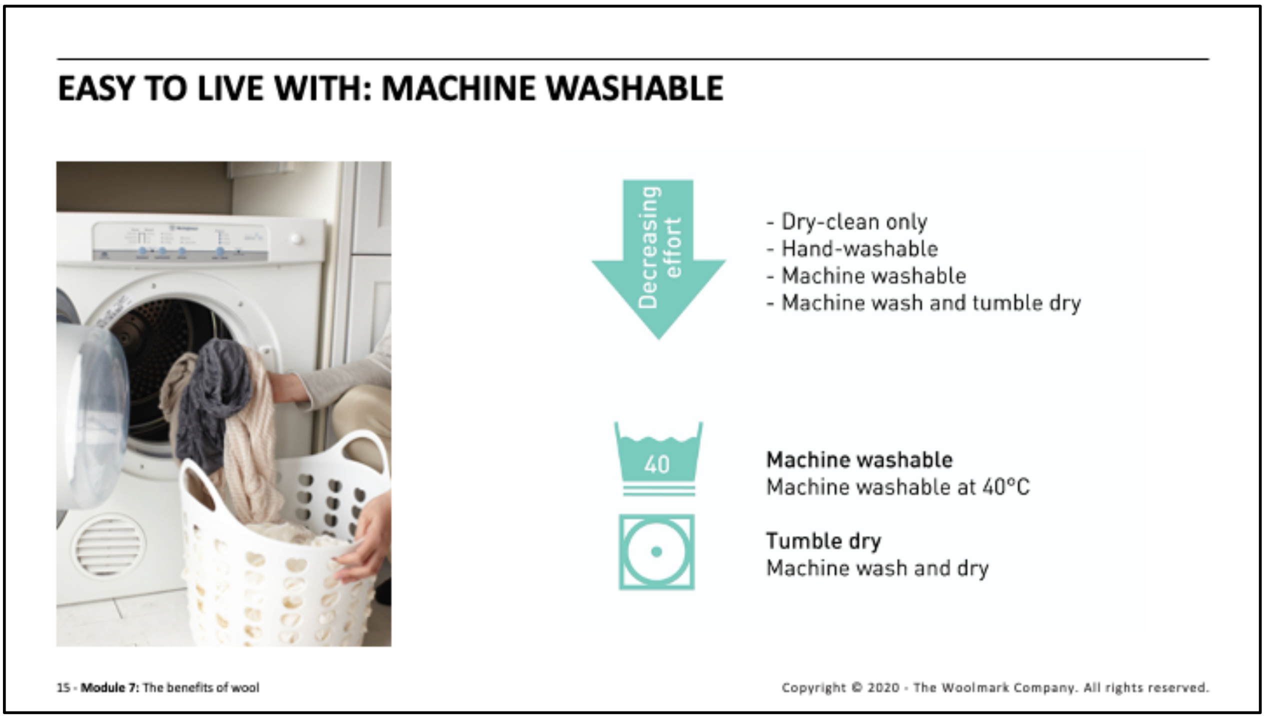
- As previously discussed, wool adsorbs water vapour produced during sensible perspiration (sweating) keeping skin dry and preventing moist skin generating 'smells' from the action of skin flora (micro-organisms)
- Wool adsorbs and binds sulphurous gases released by the body during exercise. The gases are not released until the garment is subsequently washed.

EXPLAIN THAT the ability of garments to manage odour following intense exercise has been investigated by comparing a range base layer garments constructed of different fibres. A volunteer then wore these garments during a session of high-intensity exercise on a rowing machine for 30 minutes. The garments were removed and placed in a plastic bag. The odour associated with each of the garments was evaluated.

REFER participants to the the illustration on the slide, which outlines the results of the investigation. The polyester (PES) garment smelled stronger than the other garments immediately. With time, the odour level of the garments constructed from nylon (PA) cotton (Co) polyacrylic (Pac) and polypropylene (PP) reached that of the polyester garment immediately after exercise. The wool garment remained 'odour-free' up to seven hours post exercise

EXPLAIN THAT the ability to resist developing odour during and after physical exertion, even following extended periods of time, makes wool a popular choice with hikers, skiers and other outdoor enthusiasts who can wear wool for several days of activity without needing to wash their garments to manage body odour.

NOTE THAT American garment manufacturer Wool & Price claim their wool garments (men's shirts) have been worn up to a hundred times without developing any smell. Participants can investigate these claims by following the link in their *Participant Guide* — https://woolandprince.com/pages/about



EXPLAIN THAT there are several levels of care recognised for the laundering for wool products. The amount of effort required reduces as you move through the list on the slide from top to bottom:

- dry-clean only
- hand-washable
- machine washable
- machine wash and tumble dry.

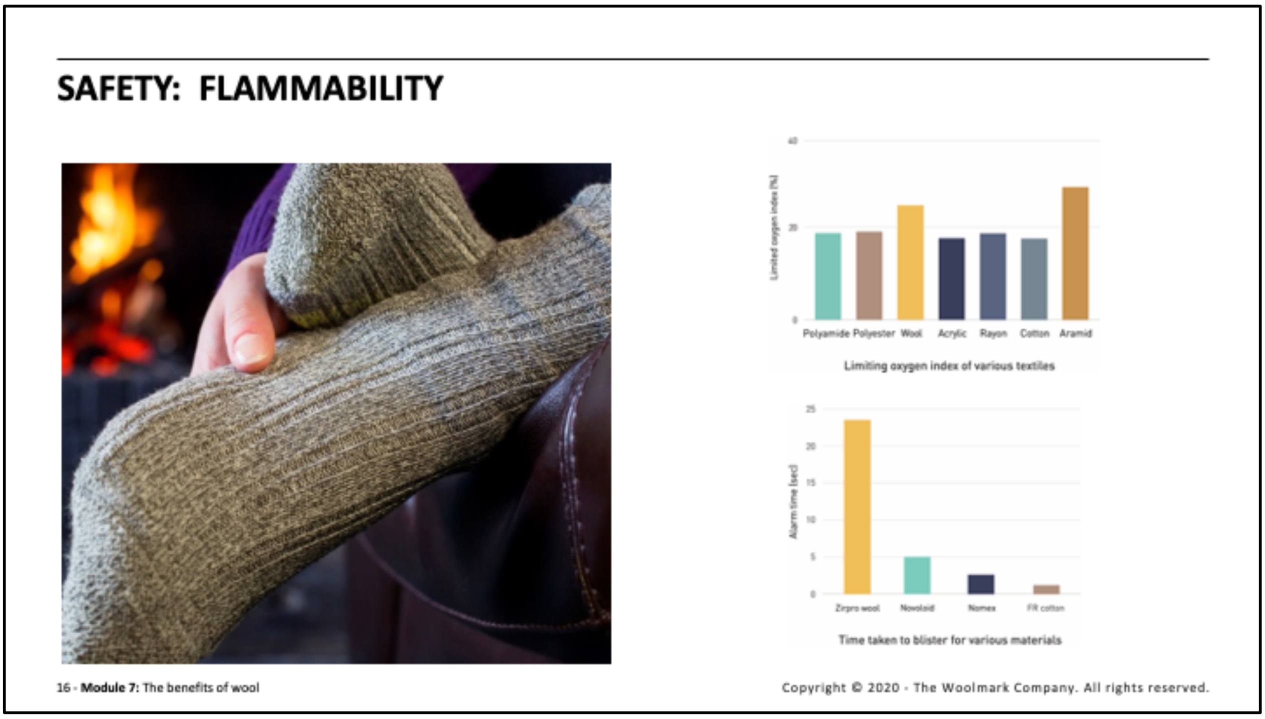
REMIND participants that as explored in *Module 6: The shrinkage of wool products*, and outlined above, some specially-treated wools are machine washable and require minimal (if any) ironing. Wool fabrics with the appropriate logos (***NOTE:*** *refer to the symbols on the slide*) on the care label can be machine washed.

EXPLAIN THAT garments with the 40°C machine wash symbol (shown top right) on the label can be washed in domestic washing machines, on a 'wool' or 'delicates' cycle at 40°C. This feature means wool garments last longer offering great value for money.

EXPLAIN THAT garments with the mild tumble dry setting (shown bottom right) on the label can be tumble dried on a low temperature setting after machine washing. This eliminates the need for dry-cleaning.

ASK *participants if they have any questions about the care of wool garments before you move on to discuss the safety related benefits of wool.*

ADDRESS *any questions in a timely manner and encourage participants to download The Woolmark Company's Wool Care Guide smartphone application.*



EXPLAIN THAT two properties of wool deliver key safety features for consumers:

- Fire resistance
- UV protection.

EXPLAIN THAT wool is well known for being fire-resistant — it does not have to be specially-treated to become non-flammable. A fabric made entirely of wool is difficult to ignite and has limited ability to sustain a flame.

REFER to the slide as you explain that the top graph shows the limiting oxygen index (LOI) of various materials. Of the materials listed, only wool and aramid (a heat-resistant and strong synthetic fibre used in aerospace and military applications) have an LOI above 20. This means only wool and aramid will naturally self-extinguish when the flame is removed.

EXPLAIN THAT the second graph compares how long it takes for different materials (and human skin) to blister, when they are exposed to heat. Wool offers additional fire protection because it chars on burning, which creates an insulating layer between the flame and the wearer.

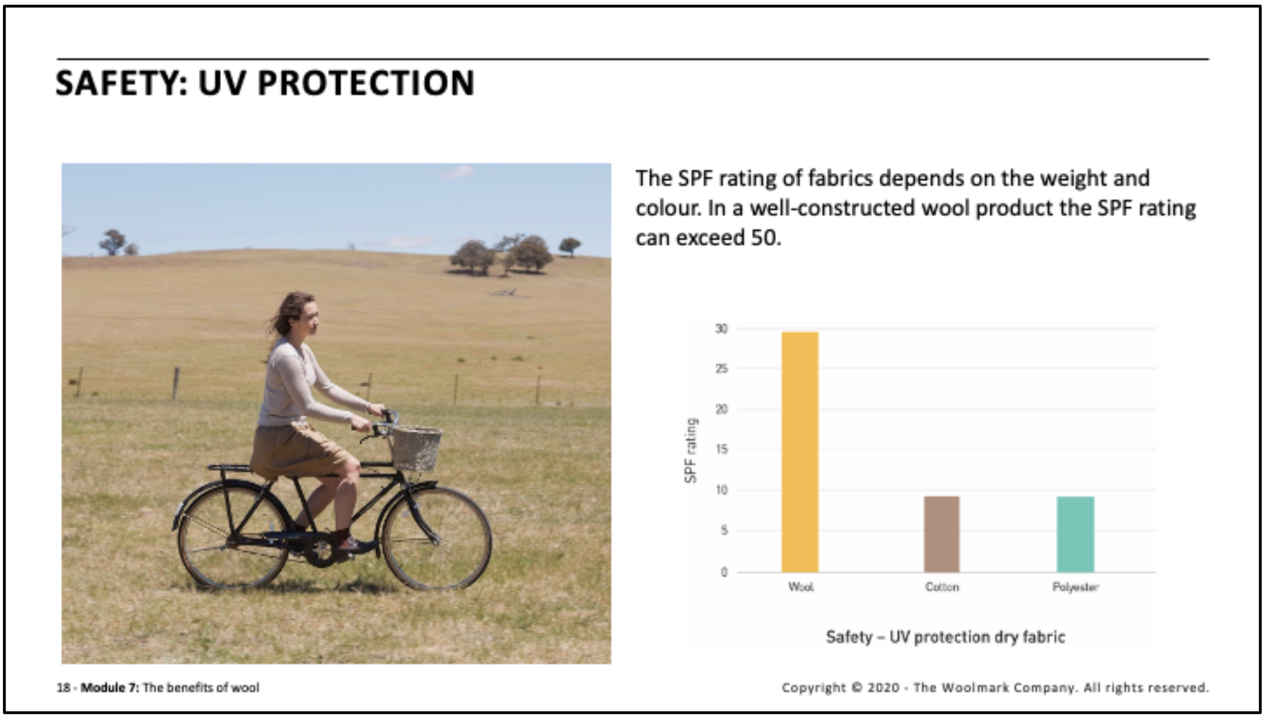
EXPLAIN THAT wool does not melt when burned and so cannot stick to the skin and cause serious burns (unlike synthetic fibres). When exposed to flame, synthetic fibres melt. As discussed in the module on fibre physics, wool has a very high melting point when completely dry, well above the temperature at which the fibre begins to decompose. The decomposition and charring occur before the wool starts to melt and stick to the skin like synthetic fibres.

INDICATE THAT because wool is naturally fire resistant it is ideal for clothing and home furnishings, protecting both your family and your home in the case of fire.

NOTE: Where possible a demonstration of the flammability of different fabrics can support the concepts covered in the slide.

__PLAY__ the Woolmark Company video demonstrates the safety features of 100% wool furnishings in the event of a fire.

Disclaimer: Wool's inherent chemical structure makes wool naturally flame resistant. It is a highly trusted natural fibre in public areas such as hotels, aircraft, hospitals and theatres. Wool is harder to ignite than many common textile fibres. Whilst cotton catches alight at 255°C, the temperature must reach 570-600°C before wool will ignite; while polyester melts at 252-292°C and nylon succumbs at an even lower 160-260°C, wool never melts so it can't stick to the skin like many common synthetics.



EXPLAIN THAT wool's ability to absorb UV rays means not only does wool keep you cool when it is hot, but it protects your skin from the sun's damaging rays. Over-exposure to sunlight is proven to contribute to skin cancer. People in the southern hemisphere have the highest incidence of skin cancer in the world. Queensland – one of the states of Australia — is the world capital for skin cancer.

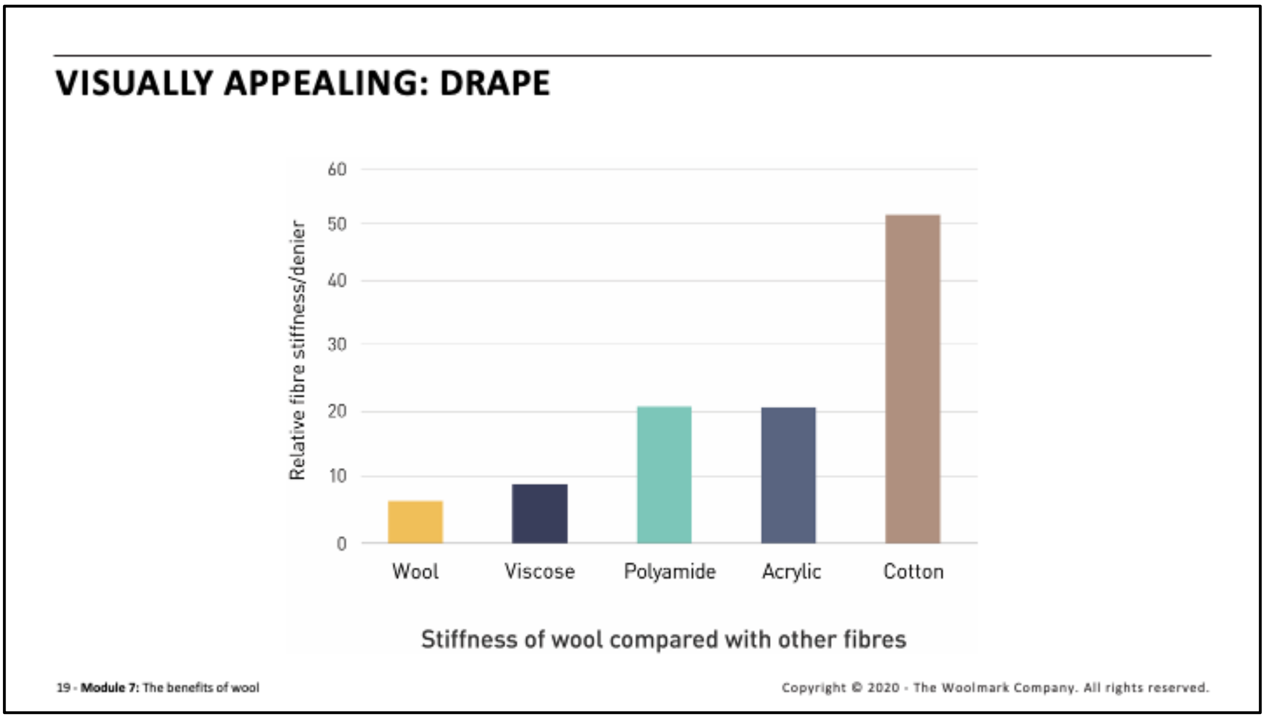
REFER TO the slide and explain that the graph shows the sun protection factor (SPF) rating of wool compared with cotton and polyester. This illustrates how wool provides excellent UV protection, which may be no surprise when you consider that sheep in Australia survive outdoors all year.

REMIND participants that the module on wool fibre chemistry mentioned that the absorption of Sun's rays including UV rays is promoted by specific amino acids. Although these amino acids degrade to colour products and the wool will eventually yellow as a result of the absorption of the UV rays, it offers the wearer good protection during the life of the garment.

MENTION THAT formerly some Australians used a wet cotton t-shirt for swimming and surfing. Wet cotton is almost transparent and offers little or no UV protection. Wool (wet or dry) protects much more effectively against UV rays.

***ASK** participants if they have any questions about the safety aspects of wool before you move on to discuss the ways in which wool is visually appealing.*

***ADDRESS** any questions in a timely manner.*

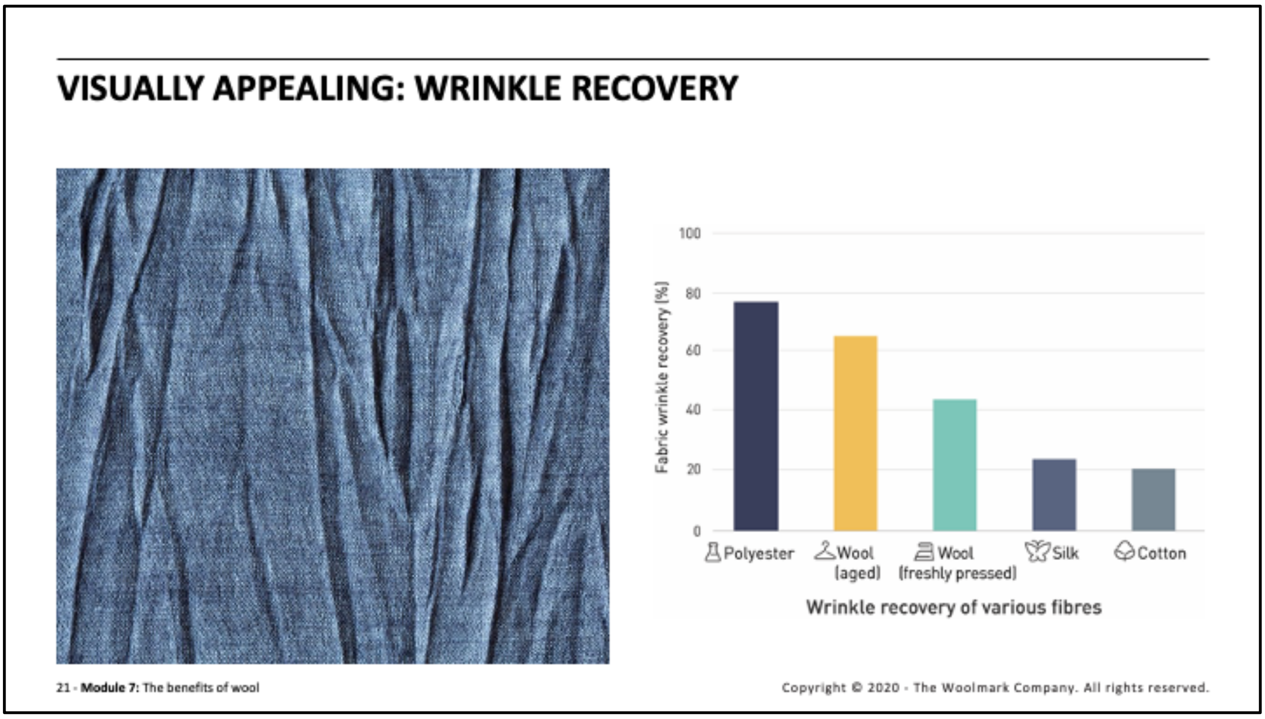


EXPLAIN THAT wool garments are sometimes considered stiff only because they feel thicker. This is because wool garments can be made with a textured surface and the crimp in the fibre tends to fill out the gaps between the yarns.

REFER to the graph, which illustrates that wool is actually less stiff per denier than other fibres and therefore more pliable in fine and lightweight fabrics.

INDICATE THAT this, coupled with the fibre’s elasticity and resilience, enhances wool’s comfort and drape (how the fabric hangs), making its appearance more appealing. In the finer microns, wool fabrics 'flow' around the body rather than just cover it, creating elegance and flair.

Furthermore, wool also has little tendency to generate static electricity because wool naturally absorbs moisture from the air. Wool garments are much less likely to spark or cling to the body.



ASK participants to reflect back on *Module 3. Physics of the wool fibre*, which explored the concepts of 'ageing' and 'recovery'.

REINFORCE that wool is one of the best fibres for recovering from wrinkle or creases formed during wear (as shown on the slide), in fact it is second only to polyester in its ability to recover from wrinkles under dry conditions.

POINT OUT that this means you can easily pack wool in a suitcase and not need to iron it when you unpack. It also means it maintains its appearance as you wear it.

REMIND participants that, as explored in *Module 3. Physics of the wool fibre*, if you allow your garment to 'age' in the wardrobe for a few weeks before wearing it, it will crease even less in wear. Less creasing and less ironing makes life easier.

EXPLAIN THAT the chemical and physical structure of the wool imparts resilience to the fibre, which is seen as wrinkle resistance and recovery in wool fabrics. Wool garments readily shed unwanted creases. Untreated wool is second only to polyester in its ability to recover from wrinkles under normal (dry) conditions. Its unique visco-elastic properties aids recovery to its normal state.

REMIND participants that as explored in *Module 3. Physics of the wool fibre* and illustrated on the slide 'aged wool' has a higher 'wrinkle recovery' than freshly-pressed wool. As wool ages, the fibre becomes more resilient.

***ASK** participants if they have any questions about the visually appealing aspects of wool before you move on to discuss the versatility of wool.*

***ADDRESS** any questions in a timely manner.*

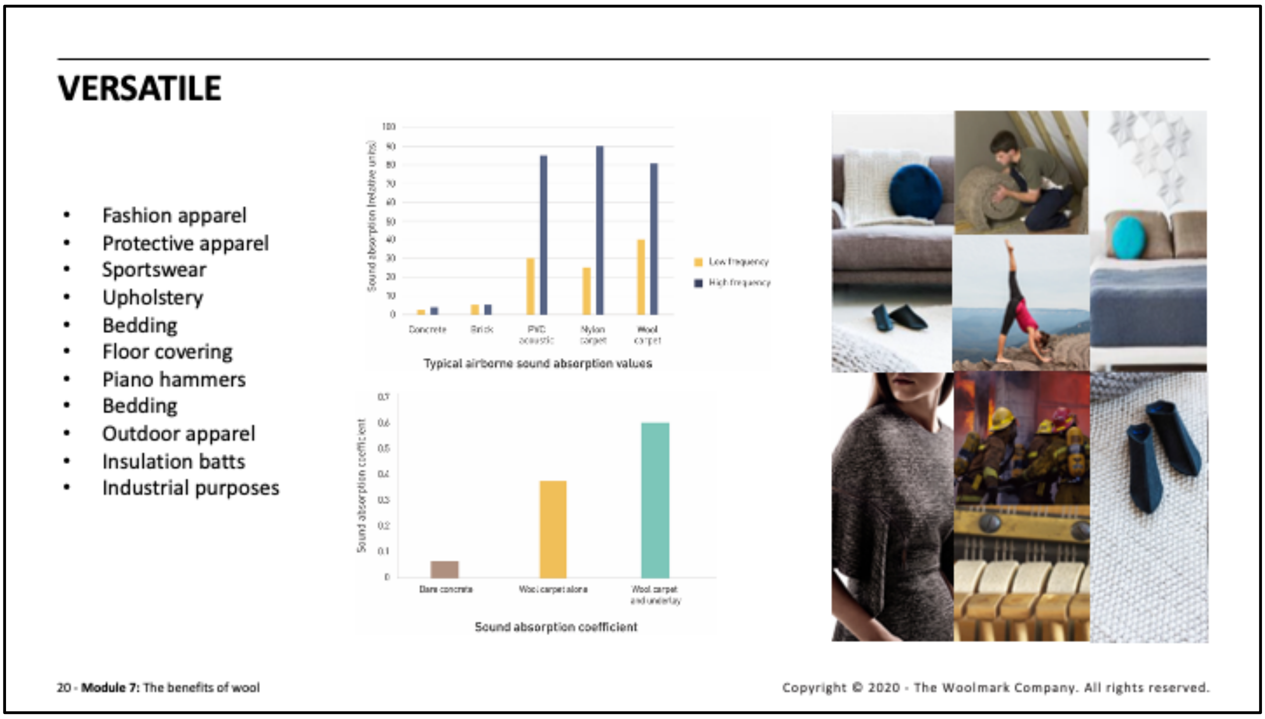
DEMONSTRATION — WRINKLE RECOVERY

- *Resources required*
- *Two fabric samples — one wool and one cotton or linen.*

***ASK** a participant to stand and hold a sample in each hand for 30 seconds in a clenched fist to scrunch the fabric.*

***AFTER** 30 seconds ask the participant to open their hands, releasing the samples.*

***ENCOURAGE** the group to observe the faster wrinkle recovery in the wool sample.*



REINFORCE THAT wool is an innovative and versatile fibre suitable for a wide range of end-uses.

INDICATE THAT wool's unique set of features means it can be used in a surprising variety of applications, as outlined on the slide.

Fashion apparel:
- Softness, easy to shape, beautiful drape and bright fast colours.

Protective apparel:
- Breathability, flame retardance and natural UV protection.

Sportswear:
- Temperature control, breathability, odour management and extensibility, comfort and flexibility.

Upholstery:
- Flame retardance, stain repellence, durability.

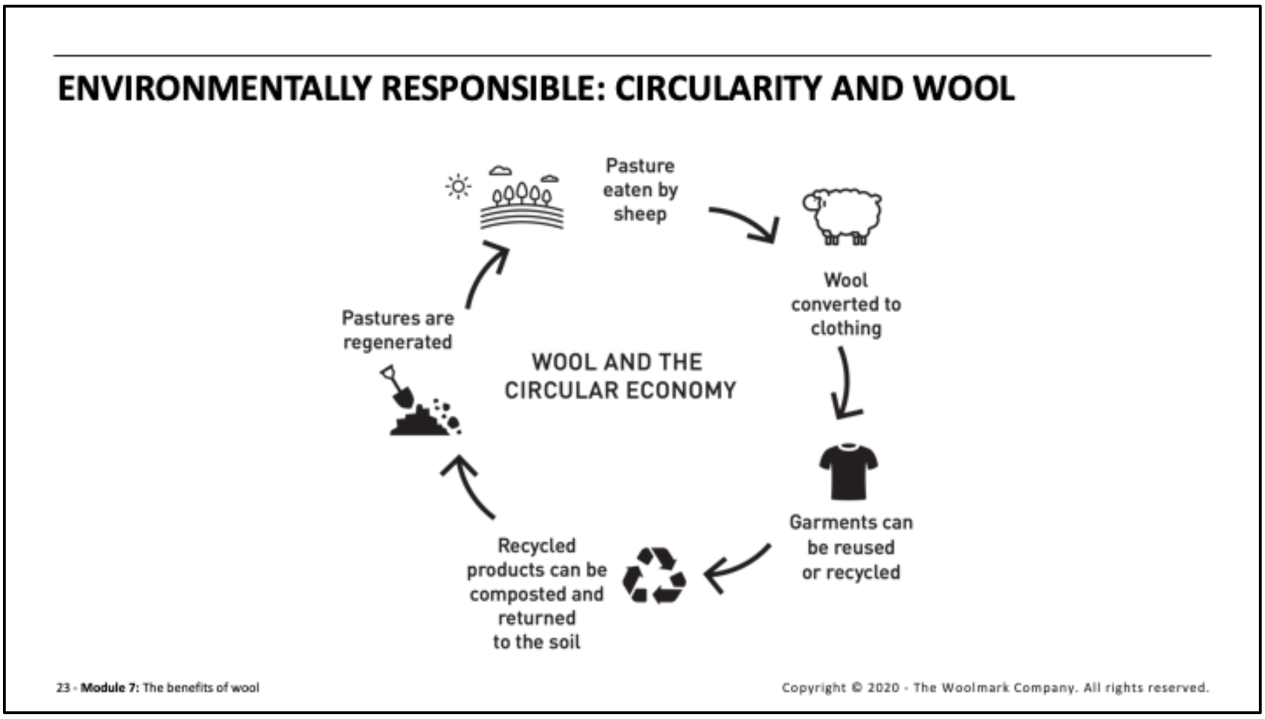
Bedding:
- Temperature control, durability, resilience.

Floor coverings:
- Flame retardance, stain repellence, durability and resilience and sound dampening (see above)

Outdoor apparel:
- Temperature control, water repellence and drape.

Insulation batts:
- Temperature control, moisture management for the building and flame retardance.

Industrial purposes:
- Sound proofing as illustrated by the graphs on the slide.



REFER TO the illustration on the slide as you note that wool is, by nature, a circular fibre. Sheep are a part of the natural cycle of life. As they graze (eat), they capture carbon stored in plants and use it to grow their wool, producing a new fleece each year after they have been shorn.

NOTE THAT a key element of the circular economy is to design waste out of the system by creating products that do not end up in landfill. There is a use for every part of a wool fleece.

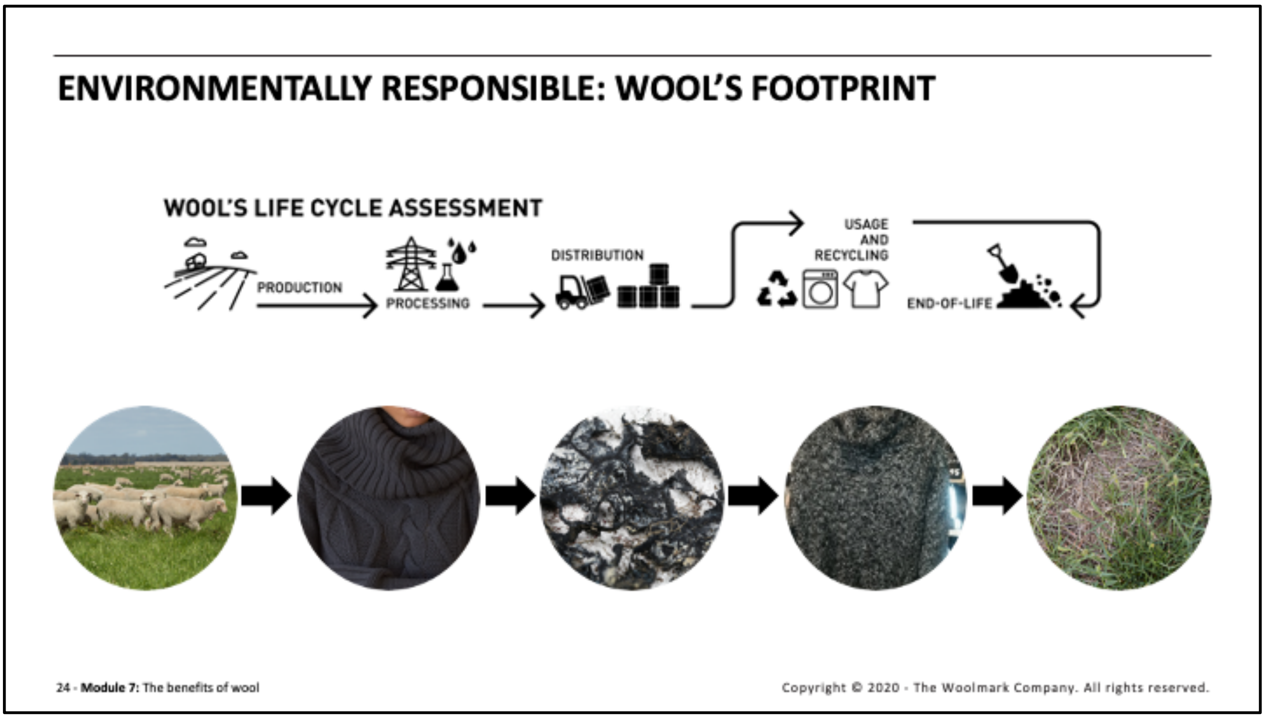
EXPLAIN THAT the circular economy also places a strong emphasis on keeping materials in use for a long time. The use phase is where wool's natural characteristics come into play. Textiles made of wool are durable and long-lasting. Surveys show consumers use woollen products longer between washes due to wool's natural ability to keep itself clean or be refreshed by airing, which reduces the energy and water impacts of woollen garments.

INDICATE THAT wardrobe studies confirm wool garments are kept longer than garments made of other fibres and enjoy multiple lives. The average life of a wool garment is 2–10 years depending on use, compared to 2–3 years for a typical cotton or synthetic garment. At the end of its first life, wool is highly valued by recyclers, extending the 'use' of the raw fibre even further. Studies have identified a high donation rate of wool garments for recycling — about 5% — which far exceeds wool's 1.3% share of virgin fibre supply.

EXPLAIN THAT the concept of 'rag pulling' or retrieval of fibre from wool products at the end of their usable life has been practised for many years. The reclaimed fibre is used to create new woollen (as opposed to worsted) products.

REINFORCE THAT recycling of wool prolongs the usable life of the wool fibre and hence the impact of the industry on the environment.

POINT OUT that the end of a circular product made of biological material, such as wool, is biodegradation. A material should only arrive at this stage when it cannot be of any further value and service. Given the right conditions, wool readily biodegrades in water and soil returning to its fundamental nutrients.



REINFORCE that despite wool being 100% natural, renewable and biodegradable, environmental ratings agencies have historically rated wool poorly against competing synthetic fibres.

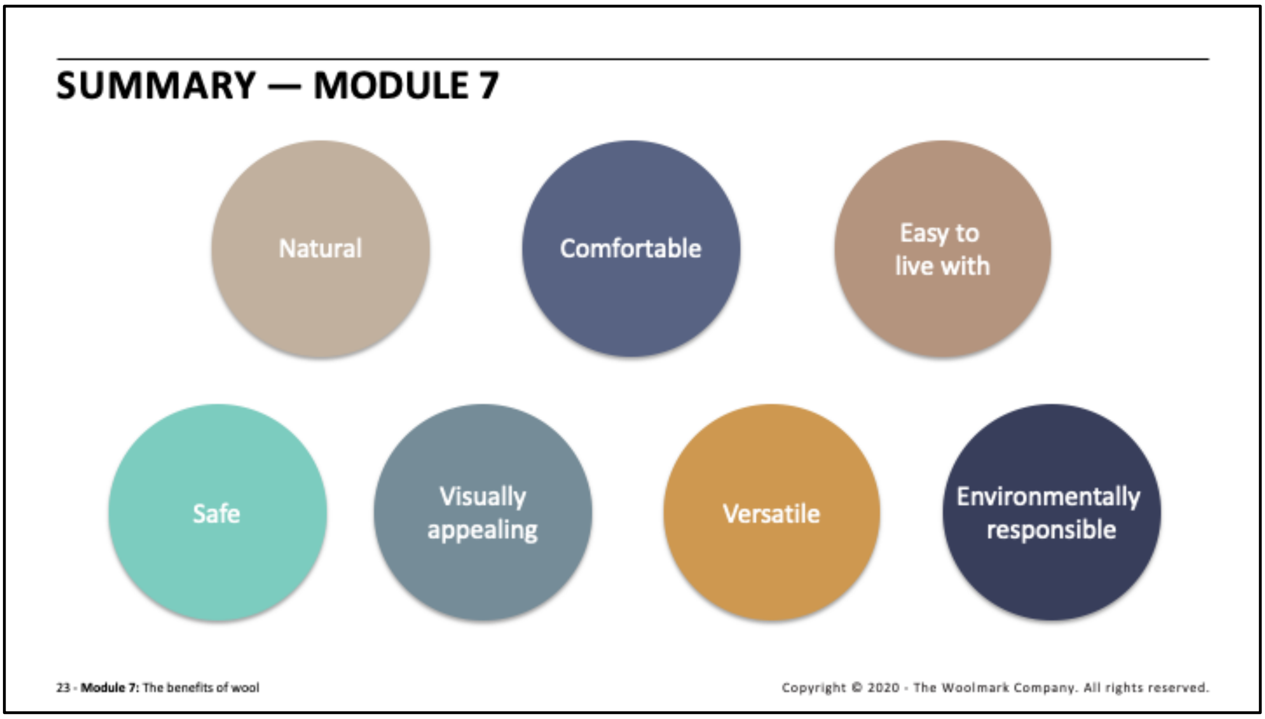
EXPLAIN THAT there are severe shortcomings to these ratings because they consider only a limited part of the supply chain and only consider some environmental impacts.

INDICATE THAT the wool industry is investing strongly in an accurate and scientifically credible assessment of wool's environmental footprint from its cradle on the farm, through all life stages to wool's ultimate biodegradation back into the soil. By working with the apparel ratings agencies, through the provision of contemporary data and sound methodology, we are seeking to improve the accuracy of the ratings.

READ ALOUD *the following quote from The Woolmark Company:*

"The wool industry is investing strongly in an accurate and scientifically credible assessment of wool's environmental footprint from its cradle on the farm, through all life stages to wool's ultimate biodegradation back into the soil. By working with the apparel ratings agencies, through the provision of contemporary data and sound methodology, we are seeking to improve the accuracy of the ratings."

NOTE THAT more information on the environmental footprint of wool can be found by following the link in their *Participant Guide* : https://www.dropbox.com/sh/c34q4y6js1e8w59/AAAwCntp0jCW5fT5XsI0coTta?dl=0



SUMMARISE the final module by reinforcing that wool is a natural fibre with a complex structure, physics and chemistry, which offer a unique set of properties and benefits for users of wool.

REMIND participants there are many reasons why people use wool and include the following:

- Wool is natural — wool is a natural fibre wool and is a renewable, biodegradable resource.
- Wool is comfortable — comfort is derived from a combination of softness, moisture management and temperature control.
- Wool is easy to live with — wool is durable, has soil and stain resistance properties, resists body odours and may be laundered easily.
- Wool is safe — wool has fire resistant and UV absorption properties .
- Wool is visually appealing — the structure and physics of the fibre impart qualities that offer a superior handle and drape. Additionally wool has good wrinkle recovery.
- Wool is versatile — wool's inherent properties mean it is the ideal fibre across a broad range of applications.
- Wool is environmentally responsible — wool's inherent properties also contribute to its environmental footprint. In addition to being a renewable and biodegradable natural fibre, wool is also recyclable. Reclaimed fibre is used in the creation of a wide range of new wool products, extending the useful life of wool.

ASK *participants if they have any further questions about the content covered in this module.*

ALLOW *time for questions and discussion before proceeding to the final slide and closing the lecture.*

REMIND participants that this module completes the course *Wool fibre science*.

ENCOURAGE participants to explore the Woolmark Learning Centre to reinforce and build on what they have covered in this course of the Woolmark Education Course — *Wool fibre science*.

Participants can register with and explore the Woolmark Learning Centre here: www.woolmarklearningcentre.com

BEFORE participants leave ensure you have collected all fibre samples distributed during the lecture.

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