The Chemical & Physical Structure of Merino Wool

In its natural state, raw wool from sheep contains a number of constituents other than the fibre. The main ones are wool grease, water-soluble material derived from perspiration (called suint) and contaminants such as dirt and vegetable matter picked up from the pastures.

These contaminants are removed during processing. Clean wool, together with other animal fibres, belongs to a group of proteins known as keratins. Unlike cotton and the majority of synthetic fibres, wool does not have a homogeneous structure. Wool fibres have highly complex physical and chemical compositions that have evolved over millions of years to protect sheep from extremes of heat and cold.

Chemical Structure of Wool

It has been estimated that wool contains more than 170 different proteins. These are not uniformly distributed throughout the fibre; proteins of different structures are located in specific regions. This heterogeneous composition is responsible for the different physical and chemical properties of the various regions of wool. The proteins in wool are composed of amino acids; so called because they contain basic amino ($-NH_2$) and acidic carboxyl (-COOH) groups. The general structure of an amino acid is shown in Figure 1.

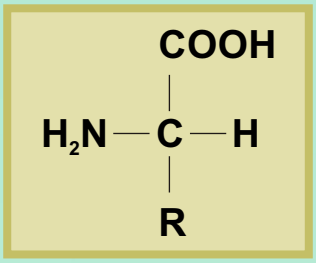
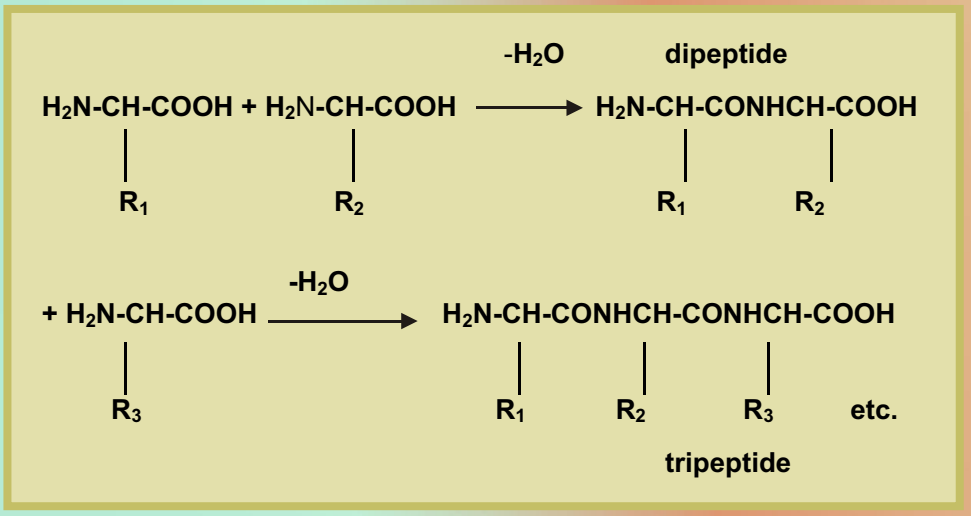


Figure 1: General Structure of an Amino Acid.

Individual amino acids differ from each other in the nature of the side group, shown as R in Figure 1. Of the 22 naturally-occurring amino acids, wool contains 18. The side groups of amino acids vary in size and can be grouped, according to their chemical properties: hydrocarbon, which are hydrophobic (water-hating); hydrophilic (water-loving); acidic; basic; and amino acids that contain sulphur. In proteins, including wool, the amino acids are joined together to form long polymer chains, as shown in Figure 2. These compounds can be regarded as polyamides because each structural unit is joined by an amide group. When the polymer chain is a protein however, the amide repeat unit (-NHCHRCO-) is called a peptide group. Figure 2 shows the formation of a simple polypeptide produced from three amino acids.

Figure 2: Formation of a polypeptide by reaction of amino acids. (R_1, R_2 and R_3 may be the same or different side groups).



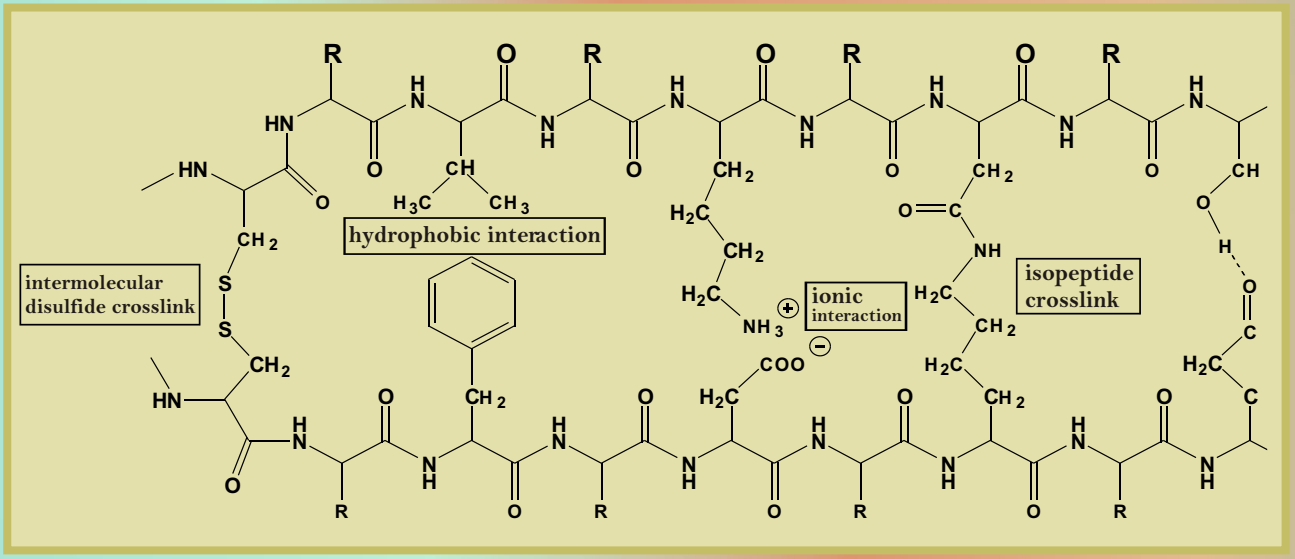


Figure 3: Bonds in Wool.

In wool, individual polypeptide chains are joined together to form proteins by a variety of covalent (chemical bonds), called crosslinks, and non-covalent physical interactions (Figure 3).

The most important crosslinks are the sulphur-containing disulphide bonds, which are formed during fibre growth by a process called "keratinisation". These make keratin fibres insoluble in water and more stable to chemical and physical attack than other types of proteins. Disulphide bonds are involved in the chemical reactions that occur in the 'setting' of fabrics during finishing. In this process, disulphide crosslinks are rearranged to give wool fabrics smooth-drying properties so that ironing is not required after laundering. Another type of crosslink is the isopeptide bond, formed between amino acids containing acidic or basic groups. In addition to the chemical crosslinks, some other types of interactions also help to stabilize the fibre under both wet and dry conditions. These arise from interactions between the side groups of the amino acids that constitute wool proteins. Thus, hydrophobic interactions occur between hydrocarbon side groups; and ionic interactions occur between groups that can exchange protons. These ionic interactions or 'salt linkages' between acidic (carboxyl) and basic (amino) side chains are the most important of the non-covalent interactions. The most important of the non-covalent interactions are the ionic, or 'salt linkages' between acidic (carboxyl) and basic (amino) side groups. The

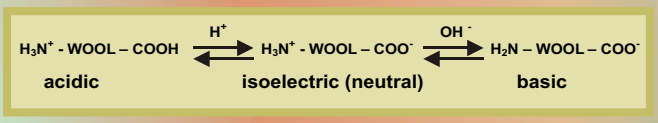


Figure 4: Amphoteric behaviour of wool.

carboxyl and amino groups in wool are also important because they give wool its amphoteric or pH buffering properties. This is its ability to absorb and desorb both acids and alkalis, as shown in Figure 4. The ionic groups also control the dyeing behaviour of the fibre, as a result of their interactions with negatively charged dye molecules.

The Physical Structure of Wool

In addition to its chemical complexity, wool also has a very complex physical structure, as shown schematically in Figure 5. A wool fibre can be considered as a biological composite consisting of regions that are both chemically and physically different.

Australian merino wool fibres range in diameter typically from 17 to 25μm. They are composed of two types of cell: the internal cells of the cortex and external cuticle cells that form a sheath around the fibre, shown in Figure 5.

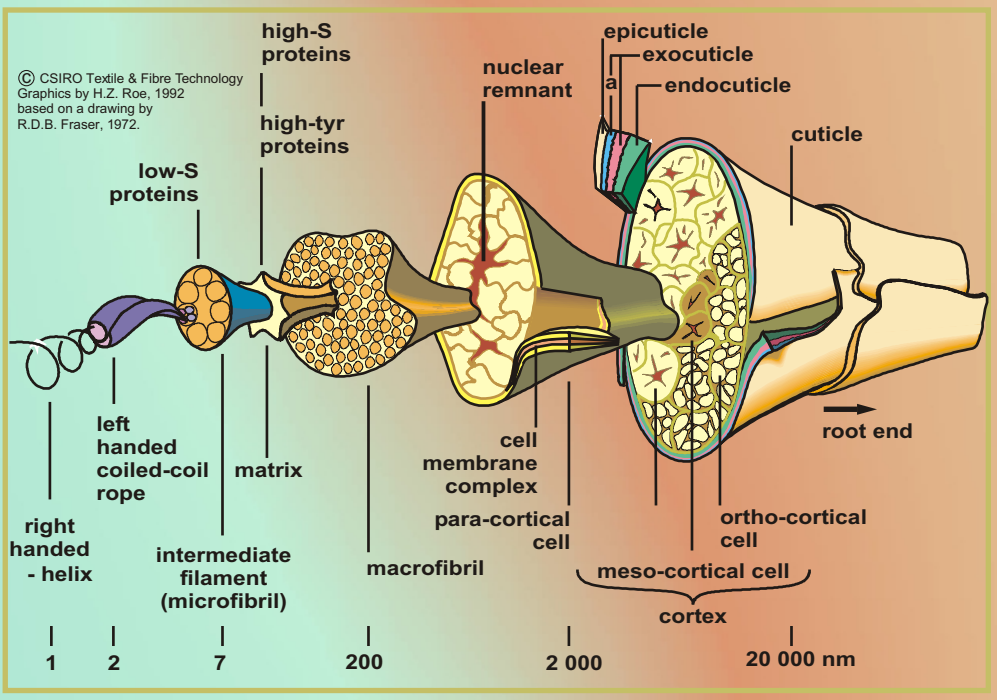


Figure 5: CSIRO schematic diagram of wool fibre.

Cuticle cells (or scales), which overlap like tiles on a roof, make wool unique amongst textile fibres. The complex physical structure of cuticle cells is shown in Figure 6. An important function of cuticle cells is to anchor wool fibres in the skin of sheep. The exposed edge of each cuticle cell points from the fibre root towards the tip. This gives rise to a larger surface frictional value when a fibre is drawn in the against-scale direction than in the with-scale direction. The frictional difference helps to expel dirt and other contaminants from the fleece, but it is also responsible for wool's property of felting when agitated in water. This characteristic, which is not shared by any other textile fibre, enables fabrics with very dense structures to be produced, such as blankets, felts and overcoat materials. When felting is regarded as undesirable (for example in knitted garments that will be machine-washed), processes are available to remove the frictional difference and make wool shrinkresistant. The fibre surface is also largely responsible for the natural softness of wool and its property as one of the smoothest textile fibres.

Even after the natural wool grease has been removed by scouring with a detergent, wool fibres are relatively difficult to wet compared with other textile materials. This natural water repellency makes wool fabrics 'shower-proof ' and able to resist water-based stains. This property is the result of a waxy, hydrocarbon coating that is chemically bound to the surface of each scale. The coating survives processes such as dyeing and can only be removed by a severe chemical treatment.

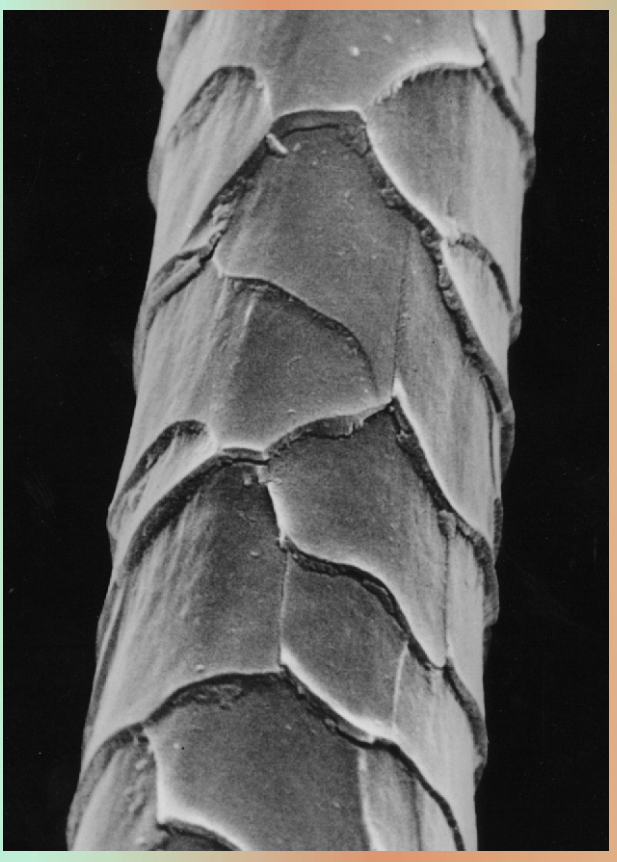


Figure 6: SEM of wool fibre.

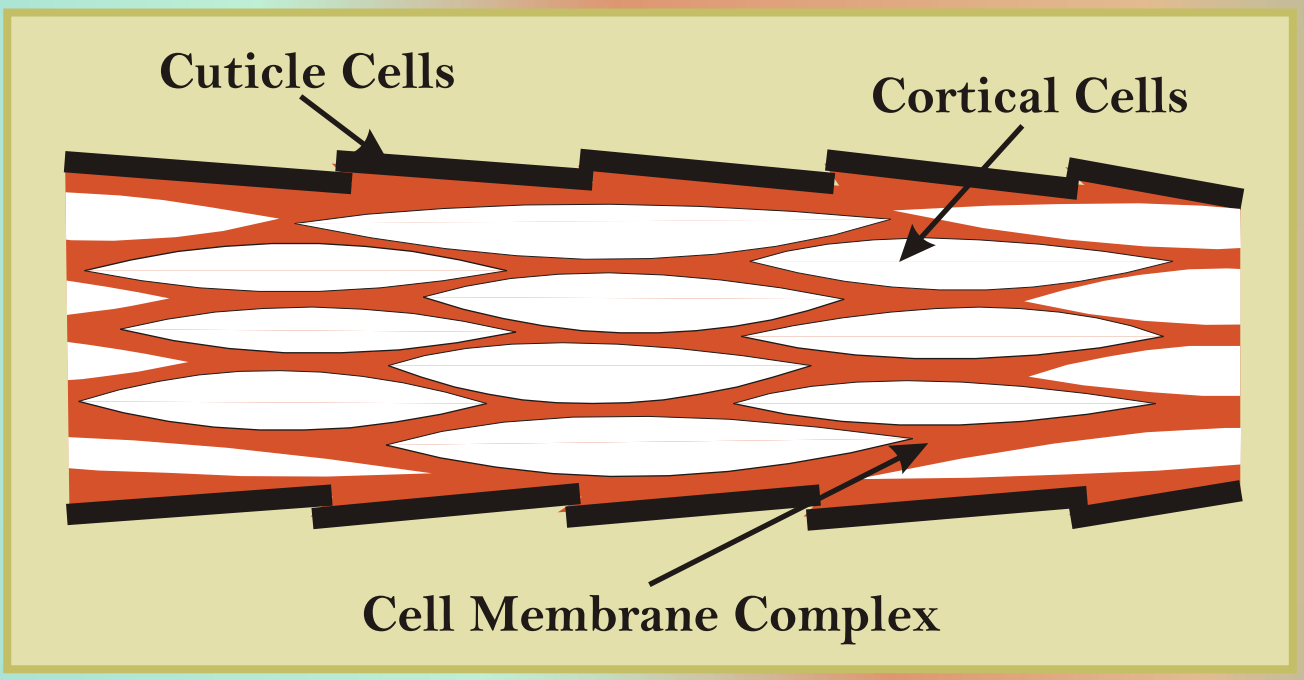


Figure 7: Schematic of a wool fibre showing cuticle and cortical cells.

The cortex of wool comprises approximately 90% of the fibre. It consists of overlapping spindle-shaped cells cortical cells, shown schematically in Figure 7. Both the cuticle and cortical cells have highly complex substructures, as shown in Figure 5.

Cortical cells are held together by the cell membrane complex (CMC), which also separates cortical cells from those of the cuticle. The CMC is a continuous region, containing relatively lightly-crosslinked proteins and waxy lipids, that extends throughout the whole fibre. Although it comprise only around 5% of the total fibre mass, it plays an important role in the overall properties of wool. It is a region of relatively low mechanical strength in the fibre composite. When wool worsted fabrics are abraded during prolonged wear, breakdown tends to occur mainly by fracture along the boundaries between cortical cells, resulting in fibrillation. Figure 8 shows separation of individual cortical cells in a fibre taken from a severely abraded fabric.

Because the CMC is only slightly crosslinked, it is also more susceptible to chemical attack. than other regions of the fibre; for example if strongly alkaline conditions or very high temperatures are used during fabric manufacturing processes. Being the only continuous phase in the fibre, it also provides a channel by which dyes and chemicals can diffuse in and out of wool.

Fine wool fibres contain two main types of cortical cell (ortho- and para-). In the case of merino wool, these are arranged bilaterally. Coarser types of wool (diameters >25μm) tend to have less distinct segmentation of the two types of cortical cells. The bilateral segmentation of merino wool is associated with the highly desirable natural crimp of the fibres. An interesting feature is that the orthocortex is always orientated towards the outside radius of the

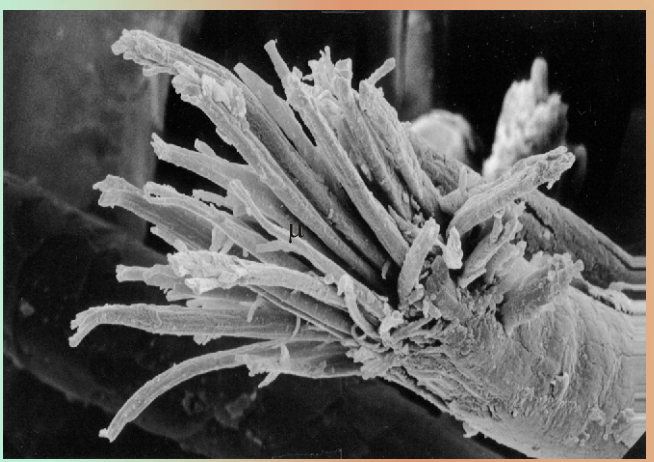


Figure 8: SEM showing fibre fibrillation along cortical cell boundaries following prolonged abrasion.

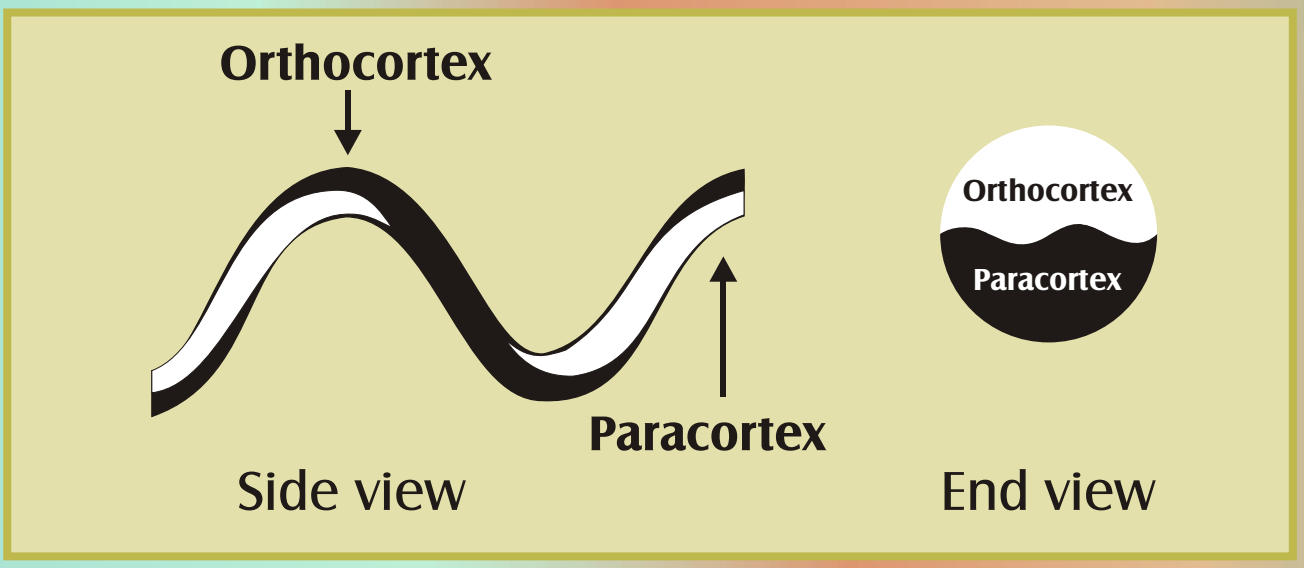


Figure 9: Diagram showing relationship between ortho/para segmentation and crimp in a merino fibre.

crimp. This occurs as a result of the two segments rotating around the fibre in phase with the crimp, as shown in Figure 4.

The structure of the proteins in wool differs between the various regions of the fibre. Some of the proteins in the microfibrils are helical, like a spring, which gives wool its flexibility, elasticity, resilience and good wrinkle recovery properties. Other proteins, particularly in the matrix that surrounds the microfibrils, have a more amorphous structure and are responsible for wool's advantage over other fibres of absorbing a relatively large amount of water without feeling wet (up to around 30% of the mass of the dry fibre). The matrix proteins are also responsible for wool's property of absorbing and retaining large amounts of dyestuffs.

Wool, a fibre that has evolved over thousands of years to insulate and protect sheep, is the most complex and versatile of all textile fibres. It can be used to make products as diverse as cloth for billiard tables to the finest woven and knitted fabrics. The insulating and moisture absorbing properties of the fibre make fine wool products extremely comfortable to wear. The chemical composition of wool enables it to be easily dyed to shades ranging from pastels to full, rich colours. It is indeed justified to call wool: "Natures Wonder Fibre".

Further Reading:

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