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More On Moisture:
Cohesive, Temporary, or Permanent Set and Hygral Expansion

One doesn't usually read back issues of the Textile Research Journal (published by the Textile Research Institute in Princeton, New Jersey) for the humor. Nor does one expect smiles and laughter from an article co-authored by Werner von Bergen, the renown editor of the multi-volume Wool Handbook (published by John Wiley and Sons, New York, 1963). Yet von Bergen's article[1] on hygral expansion in TRJ provides both amusement and insight into the behavior of worsted fabrics when the relative humidity changes. Illustrated is a beautifully finished man's suit jacket (20% RH) and the same jacket, rumpled and puckered, when it was subjected to high 90% relative humidity (Figures 1a and 1b). One can imagine the dismay of a senior scientist and textile technologist emerging from a first class Pullman railroad car for a winter Florida vacation with such disheveled attire. Dr. von Bergen's work on this topic, together with those of his colleagues and, more recently, his successors in the textile field, is actually quite worthwhile--and cogent reading for textile and costume conservators today. The effects of set and dimensional stability not only answer questions pertaining to relative humidity for worsted garments and textiles, but they also begin to answer three important questions for conservators:

1) what is the effect of heated deionized wash water on wool?
2) can you reset the dimensions on a tapestry or carpet that has been stretched out of shape (creep)?
3) will the new "wet" dry-cleaning techniques damage antique textiles?

This paper will review the properties described in the literature as set and especially the hygral expansion of wool. It will discuss the implications of these properties for the appearance of costume and textiles in museum collections. A glossary is provided as an aid to readers; a bibliography is included for further reading.

In the case of Dr. van Bergen's worsted jacket, the wool fabric had elongated with an increase in relative humidity. By contrast, the cotton sewing thread became stronger and slightly swollen at high humidity; any temporary tension produced by the winding of the thread on the bobbin or by sewing was relaxed with the increase in moisture content. Where the gabardine was restrained by seams and tapes, it grew in "the third dimension"--bubbling outward. Thus, the jacket puckered along the back seam and bagged out along the bottom hem. To some extent Dr. van Bergen and his colleagues understood this problem.

Textile scientists and technologists had studied the effect of moisture on mechanical properties for several decades (see the Textile Conservation Newsletter No. 28, Spring 1995, p14-28 for a review). Under high (90-100%) humidity conditions, the wool fiber's stress-strain curve becomes flat (Figure 2). Consequently, the same stress or weight on wool can cause the fiber to stretch from its initial 5% extension to almost 30% extension. That is, the fiber can grow longer of its own accord. Yet there is a difference between the reaction of an individual fiber and of a woven fabric. Wool fabric exhibits "the dry extension paradox"--because the drier wool cloth (in equilibrium with 65%RH) elongates more than the wet cloth at low stress loads. In Figure 3a, stress (weight load) at low levels produces more extension on wool cloth at 65%RH than on wet cloth while it is the opposite for the wool fiber--fiber at 65%RH stretches less than wet fiber. If more stress is applied, the comparative extensibility of the cloths is reversed and wet wool fabrics are more

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[1] von Bergen, W. and C.S. Clutz, "Dimensional Stability of Woolen and Worsted Fabrics," Textile Research Journal, vol. 20 (August, 1950):580-591.

Figure 1a. Freshly pressed jacket at 20% Relative (after van Bergen and Clutz)

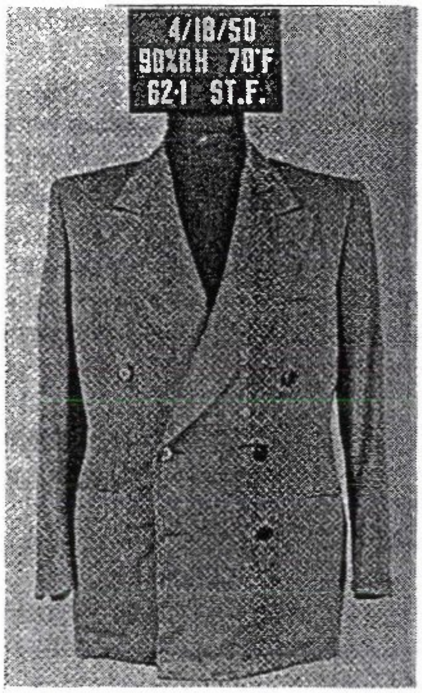

Figure 1b. Slightly closer view of the same jacket as in Figure 1a at 90% Relative Humidity (after van Bergen and Clutz)

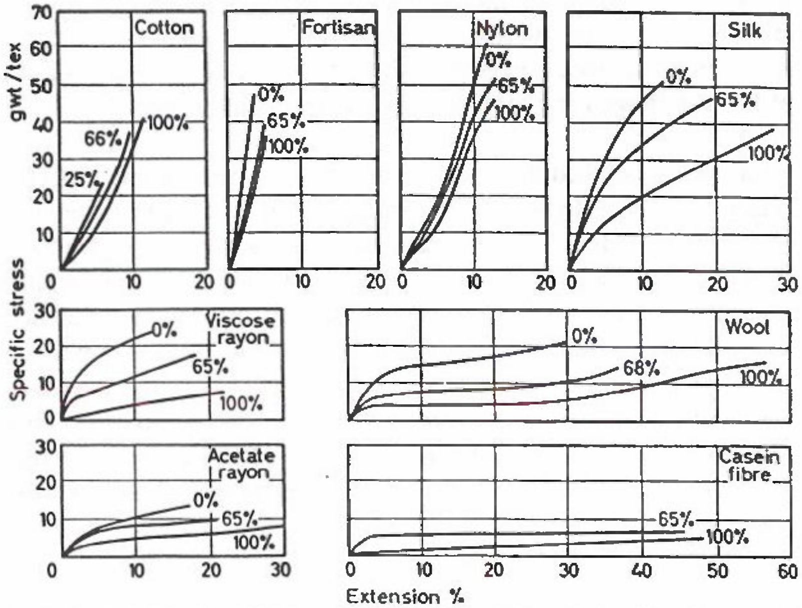

Figure 2. Stress-strain curves of major fibers at various humidities (after Morton and Hearle)

easily extended than dry ones. At the top of Figure 3b, the larger stresses produce weaker, stretchier wet fibers and wet cloths: both the wet fiber and the wet cloth will break with a smaller load at a level of greater extension. Because the garment was relatively lightweight, the load (weight of the jacket) should not have produced dimensional instability at high humidity, given the dry extension paradox.

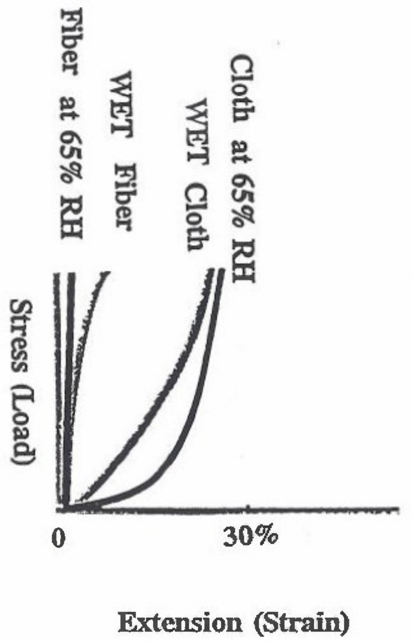

Figure 3a. A comparison, at low stress levels, of load-extension curves for wool single fibers and for wool cloth at 65% relative humdity and in a wet state. Load axes for fiber and cloth use different scales. (after Anon., Wool Science Review, 1963)

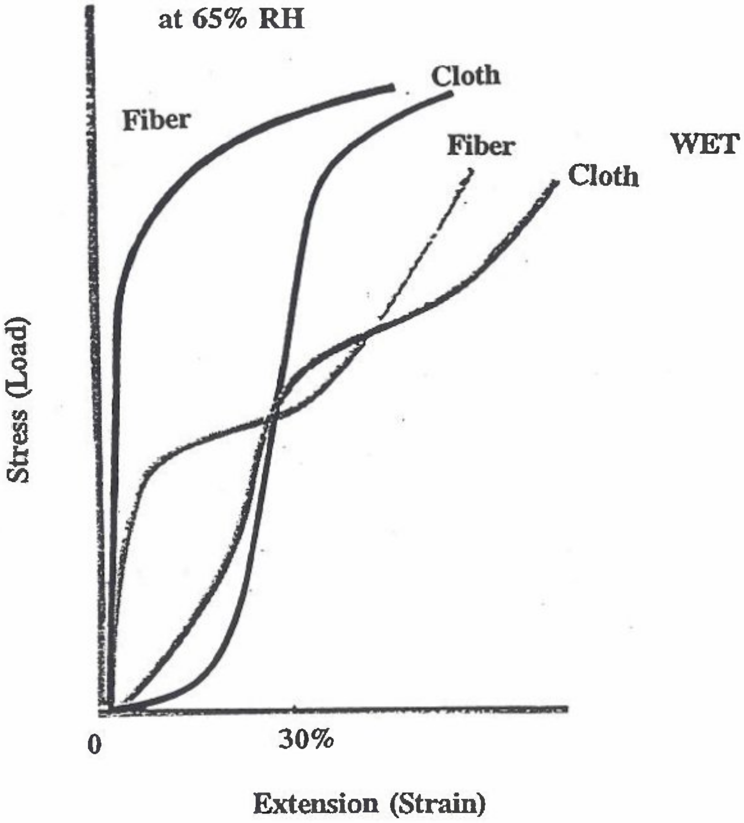

Figure 3b. A comparison, at low and high stress levels, of load-extension curves for wool single fibers and for wool cloth at 65% relative humdity and in a wet state. Load axes for fiber and cloth use different scales. (after Anon., Wool Science Review, 1963)

What Dr. van Bergen observed with his jacket study was actually a special and peculiar property most noticeable in the areas of uncut, unrestrained worsted cloth: a dimensional movement of wool fabric by 2%-4% as a reaction to changes in relative humidity. He also distinguished the phenomenon from either relaxation shrinkage or felting shrinkage. In his study, the dimensions of the fabric actually see-sawed (Figure 4). With unrestrained fabric lengths, worsted cloth could grow and shrink repeatedly, a phenomenon he termed "R.H. motion of the fabric." Cycling 12 oz. gabardine between 20% and 90% produced fluctuations in size of 4.4% if the fabric was resting flat on a table, but 5.7% if it was suspended. Steam pressing and relaxation shrinkage were repeatedly reversed with "water relaxation." The changes in dimensions might be related to creep, elongations due to constant stress over time (Figures 5a and 5b), or to elastic and plastic deformations, the sort of cycling of stress on and off that produce elongations (Figure 6), but the dimensional instability described by Dr. van Bergen is primarily moisture-related, a function of the wool cloth and its equilibrium with various relative humidities; it can occur when the fabric is at rest, flat on a table!

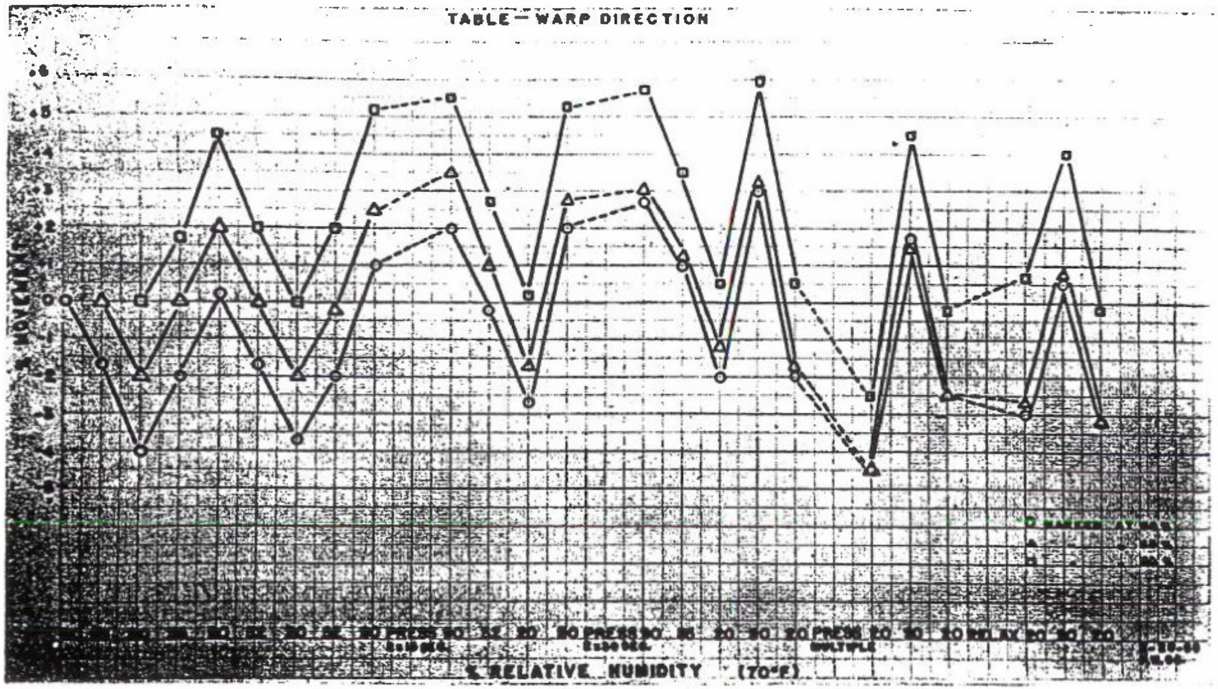

Figure 4. Movement of a 13oz. gabardine cloth, flat on a table, with changes in relative humidity (after van Bergen and Clutz).

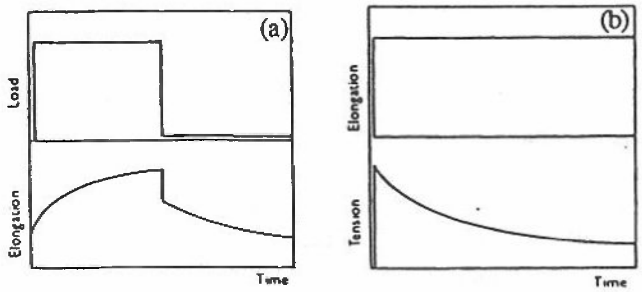

Figure 5. Viscoelastic behavior through time: a) Creep under constant load and recover under zero load; b) stress relaxation under constant tension (after Morton and Hearle).

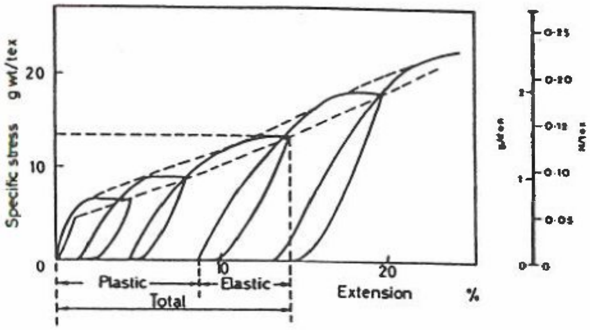

Figure 6. Stress-strain loading and unloading of viscose rayon. There is both elastic recovery and more permanent plastic deformation (after Morton and Hearle).

Other wool scientists and technologists also studied the problem of dimensional stability. Margareta Cednäs distinguished four types of shrinkage for wool fabrics: felting shrinkage due to the directional entanglement of the fibers; relaxation shrinkage when fabrics, strained during manufacture, are relaxed by water or by wet steam; a dimensional change caused by a change in moisture content; and a "press shrinkage" during steam-pressing. She focused upon the effect of cloth construction and the effect of finishing processes (dyeing, etc.) and tailor pressings to induce permanent and temporary set. Like Dr. van Bergen, she expressed concern that the subsequent moisture conditions be correlated to the construction of a garment or "make-up" of fabrics into clothes. Her assessment, unlike Dr. van Bergen's, was conducted on the advent of durable-press cotton fabrics. She was confident that the shrinkage, handle, and crease-recovery research incorporated factors useful in the future treatment of other fibers.

Meanwhile, at the C.S.I.R.O. Wool Research Laboratories in Australia, Dr. Baird, was able to characterize the peculiar, reversible dimensional changes observed by Cednäs and van Bergen, now termed hygral expansion, as a function of moisture content, fiber swelling, and weave crimp. Dr. Baird plotted the change in length of a worsted fabric against its moisture regain (Figure 7a). He demonstrated that a maximum of expansion corresponds to about 20% moisture regain, after which a slight contraction occurs. In part, Dr. Baird's explanation of fiber swelling pertains to the different longitudinal effects of ortho and para-cortices of the wool utilized for worsted yarns. Comparing the fibers of a yarn, bent into a weave crimp, to those of a homogenous rod, Dr. Baird postulated that swelling from moisture caused the yarns' fibers to straighten, increasing the radius (R) and the yarn's length (DE) in Figure 7b. When these weave crimp forces of warp and weft swell to a level of mutual constriction, the increment in dimension ceases (Point B of Figure 7a). Any more moisture and the fabric will shrink slightly. Dr. Baird pointed out that the swelling shrinkage of section BC in Figure 7a parallels the swelling shrinkage occurring in cotton and rayon fabrics. At low moisture regains, this fiber swelling produces hygral expansion. At higher moisture regains (i.e. in equilibrium with higher relative humidities), the decrimping of the yarns takes precedent in promoting hygral expansion.

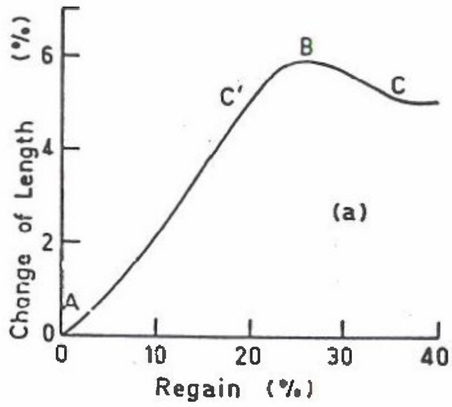

Figure 7a. Typical Hygral expansion in a worsted wool fabric (after Baird).

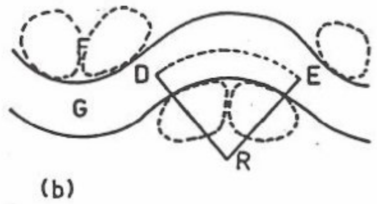

Figure 7b. Cross-sectional view of a worsted fabric (after Baird).

Thus, hygral expansion combines fiber swelling forces and yarn decrimping ones; both these forces occur with moisture adsorption and desorption simultaneously in worsted fabrics (Figure 8). Hygral expansion is the physical sum ("observed behavior") of these two types of forces in a fabric at rest when there are changes in its moisture content. In the literature, the "bent beam" analogy is used to describe both forces (Figure 9):

> In a wool fabric, bent beam forces (associated with single fibers) operate at low regains to reduce weave crimp in the yarns and increase fabric dimensions as the regain is increased, and to increase weave crimp and reduce fabric dimensions as the regain is reduced....At high regains, a point is reached with unset yarns...where a contraction in dimensions occurs as the regain is further increased....As the regain increases, the separation of the

yarn centers at the cross-over points increases, and this leads to a reduction in the spacing between adjacent threads. The opposite behavior occurs as regain is reduced.[2]

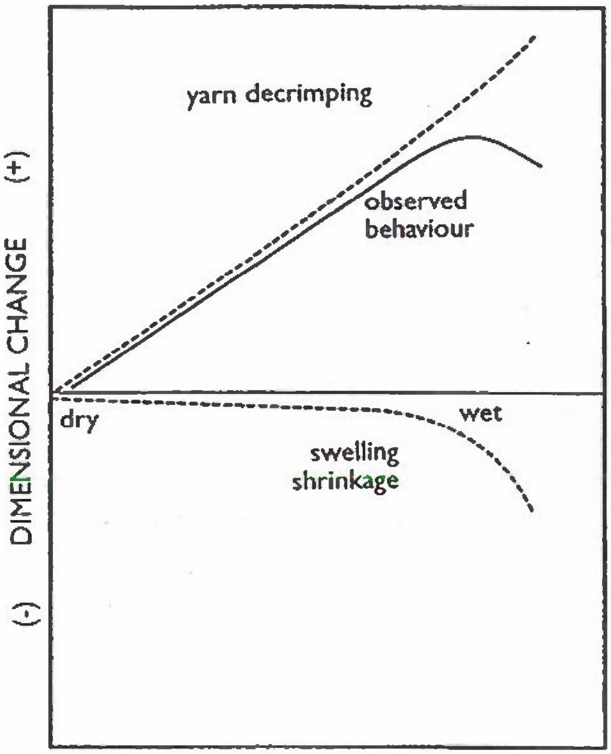

Figure 8. The Hygral expansion curve of worsted cloth is seen as the addition of the fiber swelling curve and the yarn decrimping curve. The horizontal axis is moisture regain (after Bona)

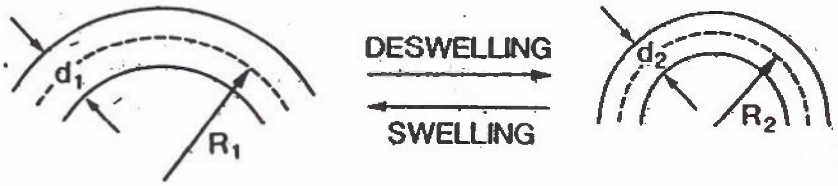

Figure 9. For a bent, elastic anistropic beam, the change in its radius on swelling and de-swelling. R = the radius of the curvature; d = the beam diameter. The realtionship of R_1 to R_2 is the same as that between d_1 to d_2 [i.e. $R_1/R_2 = d_1/d_2$] (after Cookson).

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[2] Cookson, P.G. "Hygral Expansion Behavior of Woven Wool Fabrics," Textile Research Journal vol. 60 (1990):580.

However confusing this mechanistic theory of hygral expansion appears to be, the nature of hygral expansion--the "observed behavior"--remains an important phenomenon. For costume and textile conservators seeking practical answers, the detailed, careful observation of wool scientists and technologists are themselves quite useful.

In the first place, wool technologists noticed that different worsted fabrics had different rates of hygral expansion and relaxation shrinkage (Figure 10 and Table I). Within these fabrics, the rates for the warp and the weft might not be identical. The calvary twill of Table I, for example, has a creped warp yarn; its weft yarn, more loosely twisted, is almost undeflected in the Z direction twill fabric. Those differences in the contortions of the warp and weft yarns as they interlace each other--the weave crimp--played a predictable role in the amount of hygral expansion (Figure 11). The greater a yarn is distorted out of plane as it intersects with its counterpart, the greater the weave crimp, the higher the hygral expansion--other factors being equal.

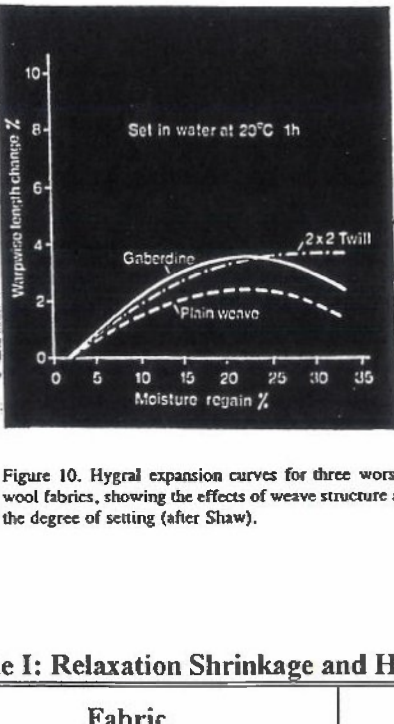

Figure 10. Hygral expansion curves for three worsted wool fabrics, showing the effects of weave structure and the degree of setting (after Shaw).

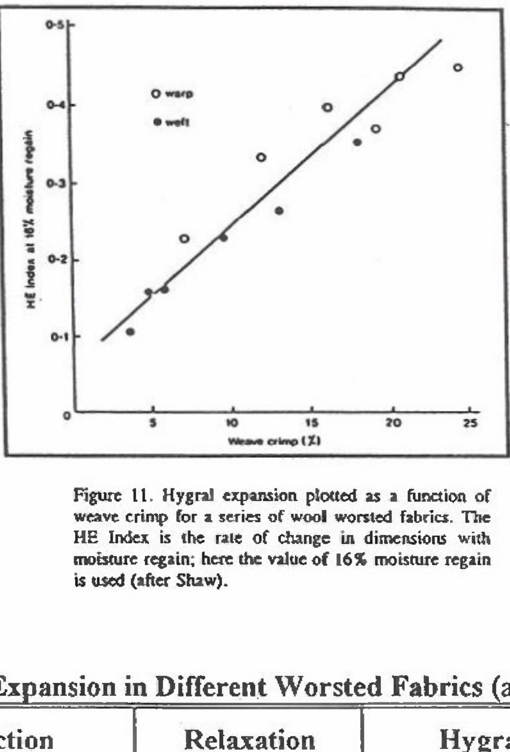

Figure 11. Hygral expansion plotted as a function of weave crimp for a series of wool worsted fabrics. The HE Index is the rate of change in dimensions with moisture regain; here the value of 16% moisture regain is used (after Shaw).

Table I: Relaxation Shrinkage and Hygral Expansion in Different Worsted Fabrics (after Shaw)

Fabric	Direction	Relaxation Shrinkage (%)	Hygral Expansion (%)
100% Wool Calvary Twill, Piece Dyed	warp weft	1.5 0.5	6.0 2.5
100% Wool 2 x 2 Twill, Piece Dyed	warp weft	0.5 -1.0*	5.5 6.5
100% Wool 2 x 2 Twill, Top Dyed	warp weft	1.0 0	2.5 2.0
70% Wool, 30% Polyester Pain Weave, Top Dyed	warp weft	1.0 1.0	1.0 1.0

*indicates expansion

There are other factors; trying to define these factors was quite difficult. Wool technologists found that attempts to replicate experiments and results had certain difficulties. Depending upon the protocols and procedures, the effect might be diminished, enhanced, reversible, or made permanent. If we look closely at the gabardine jacket in Figures 1a and 1b, we can see that part of the problem with the jacket's appearance, after all, is its lack of consistent distortion: the seams at the lapels and sleeves, for example, exhibit less change in shape than the back-seam of the garment.

In Figure 12, we see that the hygral expansion of gabardine, plain weave, and 2 x 2 twill worsted cloths are all significantly increased when they are treated for one hour at 100° Celsius. Dr. Cednäs found that the temperature of the water, the duration of the treatment, its pH, the amount of physical strain on the fabric during treatment all affected the subsequent hygral expansion of the fabric. She termed the function of these effects as the set of a fabric. Dr. Cednäs illustrated and diagramed the overall result (Figure 13). She also noted that the steam-pressings, which occur while a garment is manufactured, provided similar setting problems.

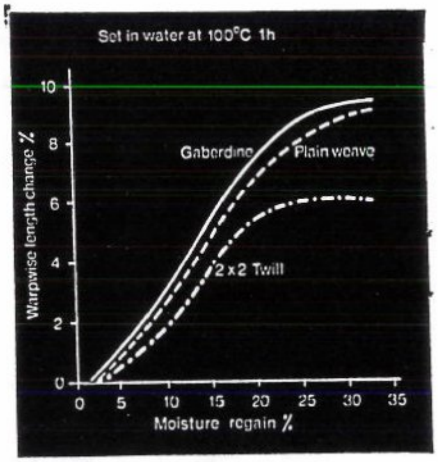

Figure 12. Hygral expansion curves for three worsted wool fabrics, showing the effects of weave structure and a high degree of setting (after Shaw).

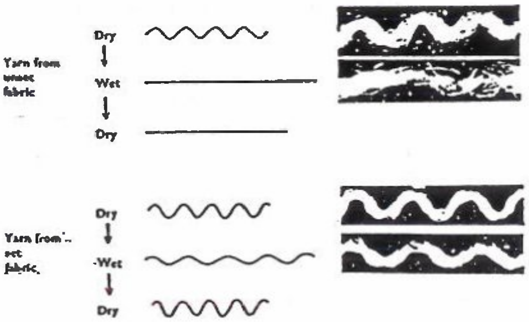

Figure 13. Diagrams and illustrations of the effect of hygral expansion on unset (top) and set (bottom) yarns from a worsted fabric (after Cednäs).

Wool technologists have subsequently catalogued a given worsted fabric as having four possible conditions: an unset state, fresh off the loom; a cohesively set state where water (saturation regain) at room temperature will relax and remove the predisposition of the weave crimp; temporary set, in which the fabric will not be altered by low temperature saturation but will be reset if it is subjected to factors more severe than those previously imposed; and permanently set fabric, the result of severe treatment. Figure 14a illustrates the mild hygral expansion (-0.37%) associated with unset fabric; Figure 14b, the higher hygral expansion (4.53%) of a temporary set fabric; and Figure 14c, the severe hygral expansion (9.73%) achieved with permanent set.

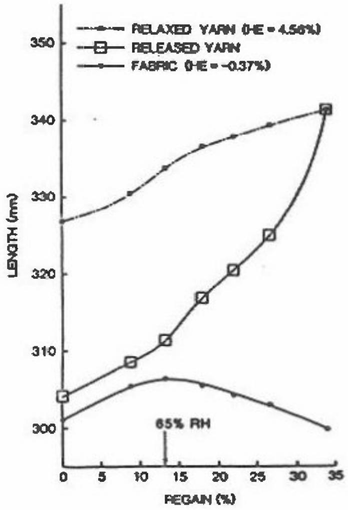

Figure 14a. Dimensional changes with regain of unset worsted fabric, relaxed yarn, and released yarn, all in the warp direction (after Cookson).

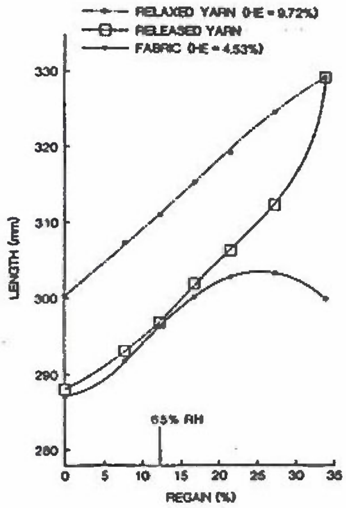

Figure 14b. Dimensional changes with regain of low-set worsted fabric, relaxed yarn, and released yarn, all in the warp direction (after Cookson).

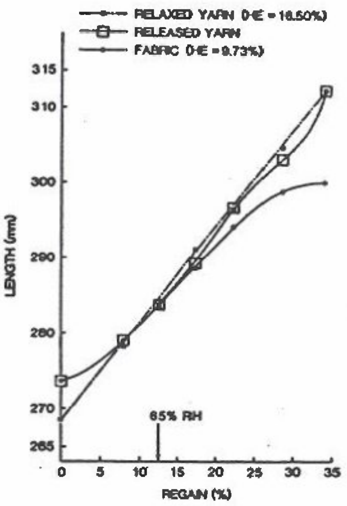

Figure 14c. Dimensional changes with regain of high-set worsted fabric, relaxed yarn, and released yarn, all in the warp direction (after Cookson).

From their cataloguing of set and hygral expansion, we see that the greater the level of set in a fabric, the more reactive its dimensions will be to changes in relative humidity if equilibrium is obtained. Also, while moisture (wetting) can be used to relax a fabric, high wash water temperatures can induce a greater dimensional instability in a fabric than those which previously existed. From a closer reading of the experimental work on the topic, we find that higher pH values (of the washing water) produce more rapid fabric setting, in a manner similar to higher temperatures. The values of hygral expansion in Table I also help us to predict the likelihood of a problem: top dyed (i.e. prior to yarn formation) fabric will be more stable than a comparable piece dyed (after weaving) cloth; fabrics with fiber blends may have proportionately lesser problems. Highly twisted creped yarns, like calvary twill warps with a high weave crimp, will be more susceptible than low weave-crimped ones, like the calvary twill weft. In this last instance, the lengthwise dimensional instability will always be of greater concern than any deviation in the weft direction. During any wetting or pressing operation, the warp direction of this fabric would be the dimensionally more fragile.

Just as interesting, wool scientists and wool technologists have observed a relationship between set formation in water and the glass transition temperature (T_g) of wool. The T_g for amorphous polymers occurs when the polymer moves from a rigid state to a rubbery one. For wool, scientists have plotted two actual transition temperatures that change with water content (see Figure 15). The condition termed cohesive set corresponds to a point below room temperature for a wet wool fiber and rapidly increases to a temperature beyond 160°C. for a totally dry one. Permanent set begins to take place in a wet fiber above 65°C. In this respect, the condition of temporary set for wool is a calculable mixture of partial permanent set and partial cohesive set; the change from cohesive to permanent set for a wool fabric or fiber is not instantaneous: the time duration is also involved.

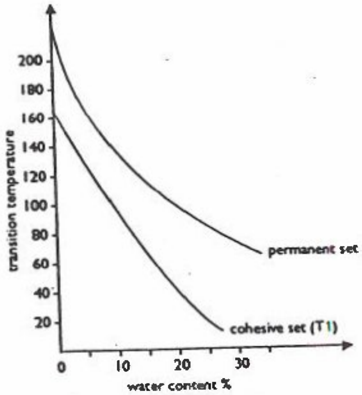

Figure 15. Curves of Cohesive Set (T_1) and Permanent Set (T_2) plotted against temperature in degrees Celsius and the moisture content of the fiber (after Bona).

Scientists see the action of water at the Tg_1 as the rearrangement of the weak hydrogen bonds. The unwrinkling of a wool bunting can be accomplished by sandwiching the creased fabric between damp blotters. The internal stress of the crease is relaxed; the flat, planar structure of the fabric is re-established. No additional heat is needed if there is enough moisture transferred from the blotters to the wool, and the wool is given enough time to relax and establish new hydrogen bonds. The permanent set (Tg_2) is related to a new and decisive ordering of cystine bonds; it cannot be altered unless the critical temperature and moisture regain levels are reached again. Although wise conservators may be reluctant to iron or to steam press antique garments, prior work of that type by a tailor or a garment maker may have induced the dimensional instability that the conservator would have preferred to avoid. Consequently, costume conservators may be dealing with Tg_1 and Tg_2 instability, a combination of cohesive and permanent sets that flat textile conservators do not normally face.

Yet the wool scientists might advise textile conservators of some equally confusing glass transition conditions: storing a wool tapestry--or exhibiting it--at a reduced ambient relative humidity raises its Tg_1, so the tapestry exists in its "rigid state" well below its Tg_1. In such a state, the tapestry develops a strain history, which wool technologists call physical ageing. By wetting out a flat, unconstrained tapestry, even at room temperature, the wool is raised above its glass transition temperature (the Tg_1). With this Tg_1 superseded, its physical ageing--its cohesive set--is erased. While raising the temperature of the water may reduce the time required in the bath for this relaxation to be complete, raising the temperature also moves the wool fiber towards Tg_2. In fact, the value of warmer water will be more to accommodate the requirements of surfactants and soil removal than for the fiber. This deageing can take place without immersion in water, because the Tg_1 is surpassed with equilibrium to 95% relative humidity at room temperature (20° C.) Thus, wool fabrics may be partly de-aged by humidification. However, recent research on wrinkles indicates that wrinkle recovery may be improved if this method of partial stress-decay is inhibited by maintaining constant ambient conditions (below Tg_1). To accelerate physical ageing, wool fabrics can be annealed: heated at a constant regain and then slow cooled. Although this effort improves wrinkle recovery, it does not survive de-ageing the fabric by wetting or pressing. Again, physical ageing is a low-set conditioned, reversible state.

Fortunately for both costume and flat textile conservators, the crimping-decrimping interchange in woven wool cloths (and the looped structure of weft-knitted machine fabrics) limit the stress-strain for most fabrics (Figure 16). Most fabrics are left well within the initial low-stress region during manufacture and use. The fiber-decrimping behavior, "the lateral movement of the fibers within yarns," and the nature of weave crimp combine to create a kind of "self-locking mechanism" at high stress levels while distorting easily at low stress-levels. This is a mechanistic description of those peculiar characteristics of wool which have made it physically such an enduring textile fiber for cloth manufacture down to the present century.

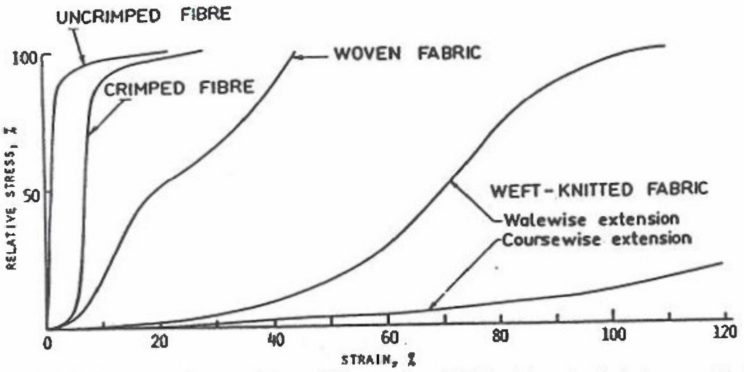

Figure 16. Typical stress-strain curves for wool fibers and wool fabrics. Note that "relative stress" is the percentage of breaking stress (after Postle et al.).

As a footnote to this discussion, it is worthwhile to mention the parameters of set in other fibers (Table II) and its common usage in hair care. While human hair has a low level of hygral expansion (less than 1%), the permanent setting of hair does indeed alter the cystine bond arrangement of hair. The effect of water on the glass transition temperatures of various natural, regenerated, and synthetic fibers are listed in Table III. The methods used to diminish the effect of water on other viscoelastic textile polymers is outside the scope of this discussion; unless the regenerated or synthetic fiber is plasticized by moisture and purposely crimped to imitate the wool fiber, it will not possess any component of hygral expansion.

Table II: Parameters of Set after Hearle, 1971

Characteristic	Type	Examples
Purpose/Result	a) Intended (desirable) b) Unintended (accidental, undesirable)	a) Domestic ironing; hair setting; commercial setting b) Wrinkling, creasing; loss of shape; overstraining during processing
Agent of Setting	a) Moisture b) Heat c) Chemical d) Adhesive e) Mechanical Stress	a) Simple hair setting; aid to ironing b) Yarn bulking; much fabric setting c) Durable press treatments; cross-linking d) Hair spray; external (to the fiber) resin treatments e) Effects of overstraining (plastic deformation)
Form of Manufacturing the Set	a) As made or obtained b) Unrestrained, free to relax c) Restrained to given form	a) Flat setting of yarn, package, or fabric b) Fabric relaxation shrinkage; skein shrinkage c) Pleating; wrinkling; yarn bulking
Durability	a) Temporary b) Cohesive, reversible, semi-permanent c) Permanent, irreversible	a) Simple hair setting with rollers or clips; reduction of twist liveliness; some wrinkling of synthetic "set" b) Domestic ironing; wrinkling and creasing; shrinkage of fibers in high bulk yarns c) Most commercial setting

Table III: Glass Transition Temperatures in Fibers and Their Lowering Due to Water*
(after Bryant and Walter)

Fiber	T_g Dry in Air, °C.	ΔT_g (Dry-Wet), °C.
Polyethylene	-25	0
Polypropylene	-20	0
Nylon 66	60	60
Polyacrylonitrile	90	20
Dynel	90	15
Dacron	100	15-20
Arnel	180	75-80
Acetate	180	75-80
Wool	>240	>200
Cotton	>240	>240
Viscose	>240	>240

* These values were calculated in 1959; more recent studies will provide more accurate values and especially the relative importance of various additives, copolymers, and finishes.

Efforts to confer dimensional stability on worsted wool fabrics continue to be an active area of textile science research. In the past, attempts to control hygral expansion included the oxidative treatments which impart shrinkage resistance, those associated with lighter fabric finishing and the use of fiber blends. With the knowledge of hygral expansion and relaxation shrinkage now evident, textile manufacturers and apparel manufacturers have ameliorated many practices in concert with after-market equipment technology. The steam-presser and drycleaner technology is matched to the fabrics they service. Currently, this technology is changing away from solvent/extraction drycleaning towards a "wet" water-based cleaning program. The impetus is funding efforts for fabric and apparel manufacturers to develop "easy care" dimensionally stable worsted products. As these developments progress, conservators will want to review carefully the studies of Dr. van Bergen, his colleagues and his successors. The older the worsted fabric, the more likely it will conform in some respect to their unstable models of physical aging.

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Glossary

Aging In the technical parlance of testing the physical properties of textiles, the term aging refers to the induction of stresses upon a fiber or fabric, as in the conditioning of a fabric into a fixed shape by a load (weight) and elongation (strain), and the maintenance of those conditions through time for experimental purposes. Physical aging is reversible. other forms of aging, like chemical and mechanical aging, may be irreversible with time and permanently degradative to the fiber and fabric.

Cohesive set Used to describe a set on wool fiber or wool cloth that is reversed with cold water. For non-wool fiber/fabrics the term used is temporary set.

Corona treatment Use of an electrical plasma discharge (a pair of electrodes) to alter the surface and chemical structure of a wool fiber; some oxidative reaction is involved due to the generation of ozone during the process.

Crease The mechanical deformation of a fabric which may or may not involve the alteration of chemical bonds between the polymer chains of a fiber

Crepe A textured fabric that may be produced by a)highly-twisted, tightly twisted yarns of a hygroscopic fiber with good elastic properties (cotton, silk, wool, rayon) woven into a simple plain, twill, or satin weave or b) normally twisted yarns woven with a sateen or plain weave with modifications that produce a textured, irregular surface with no dominant feature (aka an oatmeal weave).

Crimp The inherent curl of many wool fibers, called crimp, is a function of the internal molecular arrangement of the orthocortex and paracortex. Merino sheep wool has a pronounced crimp due to the lamination of ortho and para cortices bilaterally in the longitudinal direction. Other wools, like Lincoln, have a sheath-like tubular arrangement which produces a smoother, less three-dimensional fiber with less crimp.

Cross-linking Permanent bonding inter and intra polymer chains inside a fiber.

Cystine bonds The disulfide (-S-S-) present in wool and hair (fur) fibers which covalently links two parts of the same molecular chain (intra-chain) or two different molecular chains (inter-chain). Cystine bonds are affected chemically by alkalis and by reducing agents; such chemical rearrangements of the cystine bonds can produce a permanent set.

De-aging In physical terms, the relaxation of induced stress in a fiber or fabric by reversing previous conditioning.

Decating or Decatizing While this term can refer to simple sponging with water to establish finished dimensions, luster, hand, and finish for a worsted or woolen fabric, it is most often used to describe a formal finishing operation where hot (boiling) water or steam is passed through such a fabric after the fabric has been rolled on a perforated cylinder. A full, soft hand is produced; the set is cohesive, semi-permanent and may be removed during garment make-up. Autoclave or kier decatising at 0.6-0.7 atm with steam heat produces a permanent set (See Shaw and White).

Durable Press The use of the term "durable press resins" is a misnomer in the sense that the chemical treatment produces internal cross-links, bonds inside the cotton fiber. There is no external resin coating or adhesive. The cross-linking occurs between hydroxyl groups on adjacent cellulose chains; as a result, the cotton fabric is rendered crease-resistant.

Felting Shrinkage The interaction of heat, agitation (movement) and conditions (pH, moisture content, additives) to produce an irreversible entanglement of fibers and an irreversible contraction in fabric dimensions.

Gabardine A warp-faced twill weave fabric, generally 2/1. A Z-direction twill with S twist warp and weft produces a prominently warp-faced twill. Often fabricated with a fine dense sett; used for rainwear [?!]

Glass transition temperature (aka second order transition temperature) Viscoelastic polymers, like fibers, have a temperature point called the glass transition temperature beyond which prior straining, annealing, hardening, and set are erased. Amorphous polymers move from a glass-like state to a rubbery one, when their T_g is reached. Wool has two glass transition states: the lower one is associated with the rearrangement of hydrogen bonds, the second T_g relates to the rearrangement of cystine bonds. These glass transition temperatures are lowered by an increase in moisture content. See Table III for the effect of moisture on Glass Transition Temperature of other Fibers.

Hygral Expansion A change in fabric dimension when moisture is absorbed or desorbed. Reversible. The level of hygral expansion depends upon the weave structure of the cloth and the prior history of the cloth. Hygral expansion is not easily reduced. Technically, hygral expansion is a percentage indicating the change in length measurement:

$$\text{HE}(\%) = \frac{\text{wet length - dry length}}{\text{dry length}} \times 100$$

Permanent Set A setting or particular configuration of a structure is made irreversible. It can only be superseded or overcome by additional treatments which may be temporary or semi-permanent.

Relaxation Shrinkage The contractive recovery of fibers strained (extended) during fabric manufacture and other operations. Fundamentally irreversible. Note: "A [wool] fabric does not have a unique or absolute value of relaxation shrinkage"(see Shaw).

Semi-permanent Set A level of set that resists the effects of ordinary use or exposure, but one which can be obliterated by deliberate, comparatively severe treatments. For wool materials, the term corresponds to temporary set.

Set The stabilization of a textile material in a certain form or shape.

Sett The number of warp (i.e. ends) per inch; British terminology.

Shrink-resist Processing Wool fabrics are susceptible to felting because of the directional frictional effect (DFE) of the wool scales, especially those on highly crimped fibers. Two types of treatments minimize this problem: either *oxidation* with cold, acidified sodium hypochlorite or with gaseous chlorine or *resin deposition* to coat and mask the surface scales.

Supercontraction A decrease in length of wool fiber due to a molecular reorganization (α-keratin is transformed into β-keratin); the new molecular arrangement is described as "more disorderly." The result of prolonged treatment in boiling water. A negative set. (See Anon. Wool Science Review, vol. 21 (1962):14-26.)

Temporary Set For wool fibers and fabric, the term temporary set refers to a semi-permanent set which is stable in water at 20°C. but is released at 100°C. For other fibers and fabrics, temporary set is reversed by slight changes in temperature, in humidity, or even by slight mechanical action. Note: Temporary set in non-wool fibers and fabrics corresponds to cohesive set in wool products.

Weave crimp The deflection from plane of the warp and weft yarns due to the character of the weave structure. Weave crimp can be expressed as a percentage: $\frac{(1-p)}{p} \times 100$

where p is the yarn length in the fabric and 1, the straightened length of yarn.

Woolen A type of wool processing in which that fibers are carded, formed into a uniform mat, before spinning. Woolen fabrics are often finished by milling, fulling, and other processes that raise a nap on the fabric surface that obscures the weave structure. In medieval and Renaissance Europe, a very expensive (labor intensive) type of fabric.

Worsted A type of wool processing in which the fibers are laid parallel–combed--before spinning. Worsted fabrics are characterized by the weave structure apparent on their surface. Tapestries, wool buntings, and gabardines are examples of worsted fabrics.

Wrinkle An unintended, accidental crease. (see Postle et al. for a full discussion about wrinkles on wool fabric).

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