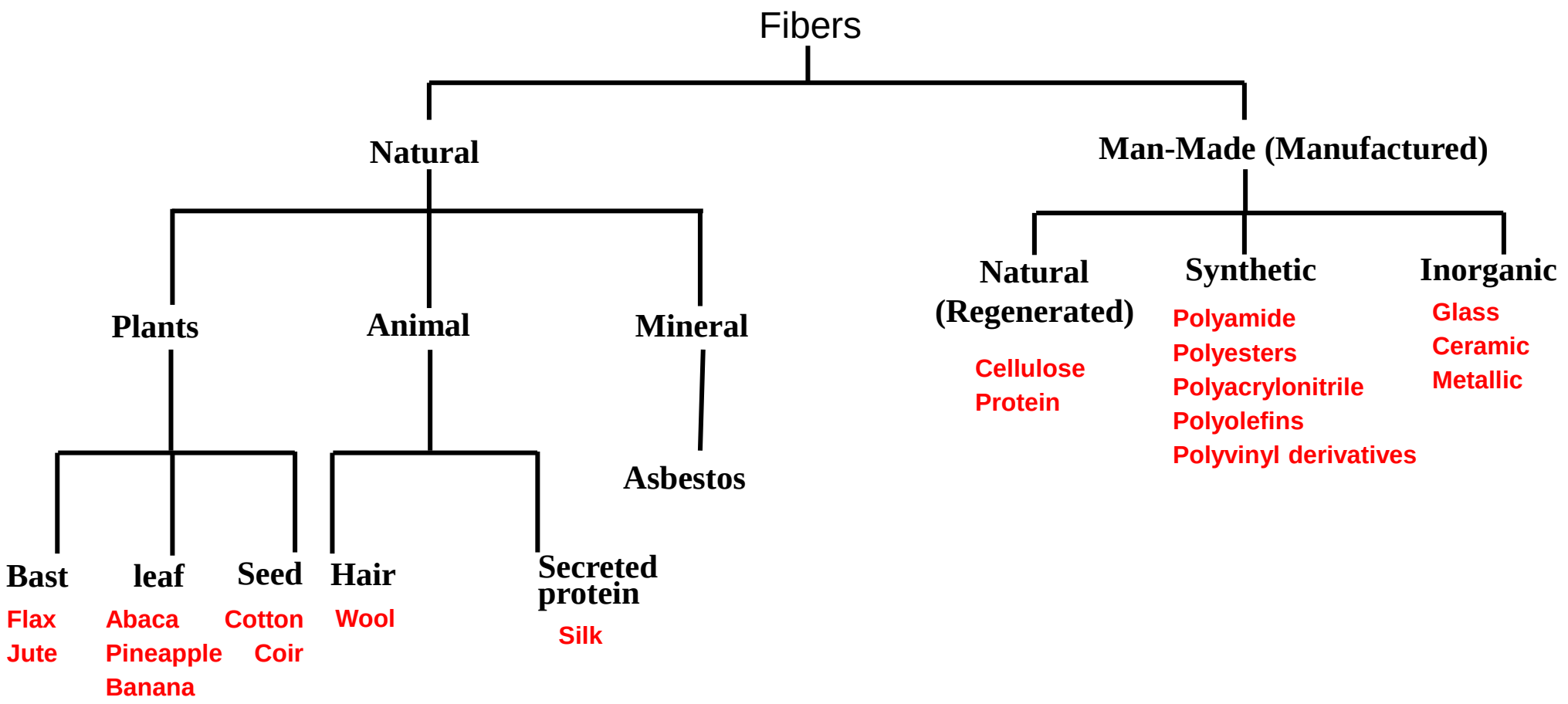
From Polymers to Fibers

Why Fibers?


Fibers
Natural
Man-Made (Manufactured)
Plants
Animal
Mineral
Natural (Regenerated)
Synthetic
Inorganic
Asbestos
Cellulose
Protein
Polyamide
Polyesters
Polyacrylonitrile
Polyolefins
Polyvinyl derivatives
Glass
Ceramic
Metallic
Bast
leaf
Seed
Hair
Secreted protein
Flax
Jute
Abaca
Pineapple
Banana
Cotton
Coir
Wool
Silk

For their significantly useful properties and vast applications

- Apparel: cloths etc.
- Domestic: carpets, curtains, bedding etc.
- Technical Textiles:
  - Protective textiles (bullet-proof vest)
  - Geotextiles (reinforcement of embankments)
  - Space (suits and aircraft structural components)
  - Medical Textiles (wound-dressing, scaffolds for tissue engineering)
  - Smart textiles (show reversible change in properties)

Hair like materials, having high aspect ratio, capable of being converted into yarns and fabrics.

Generally have following further characteristics:

- **High length to diameter ratio**
- **Strength**
- **Flexibility**
- **Elasticity**
- **Moisture absorption and transmission**
- **Dyebility**

Ensure continuity and strength along the length of fiber

↕

Liner polymers

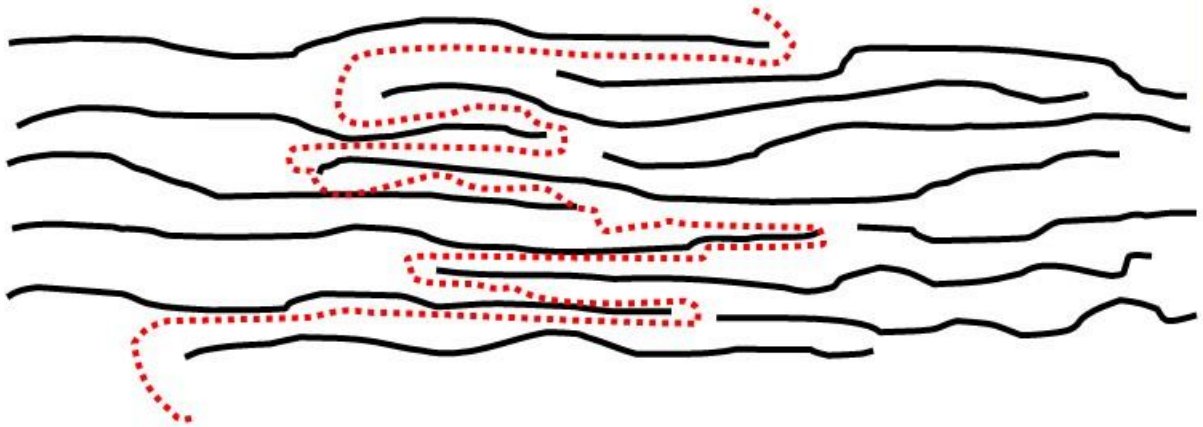
- Long chain molecules, corresponding to long fibers that make up yarns: if the molecules or fibers are too short, there will be loss of strength
- A more or less parallel arrangement of molecules
- Lateral forces to hold the molecules together and give cohesion to the structure
- Some measure of molecular movement freedom to provide necessary extensibility and some openness for moisture absorption and dye uptake

Effect of length of molecules (or fibers) on strength (a) long molecules showing cohesion (b)short molecules showing possibility of easy breakage

Characteristics of polymers influencing fiber properties

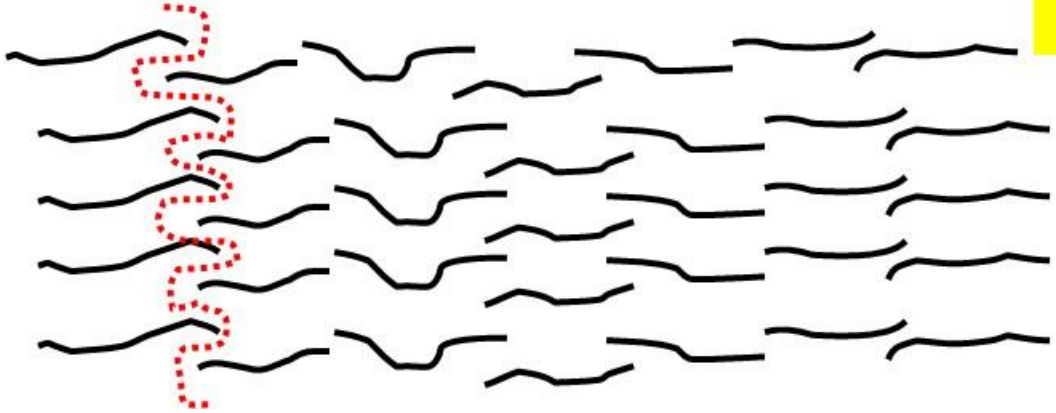
- Molecular weight
- Linearity
- Orientation / Crystallization
- Cohesion
- Melting point

Polymer's Molecular Weight



High molecular weight (long polymer molecules)

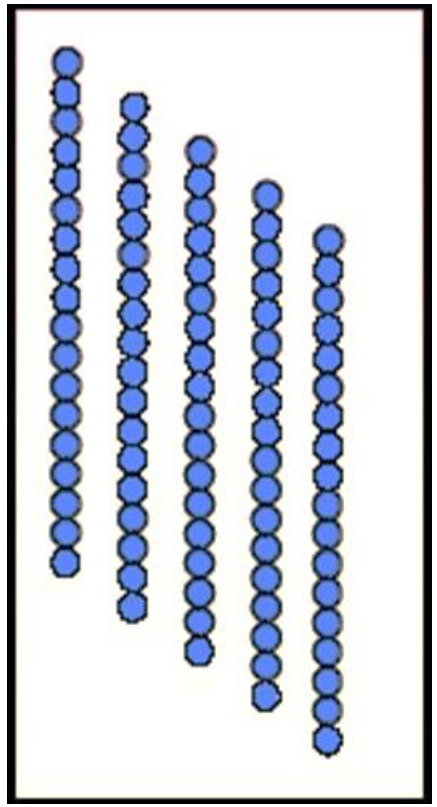
Path of break is long (strong fiber)



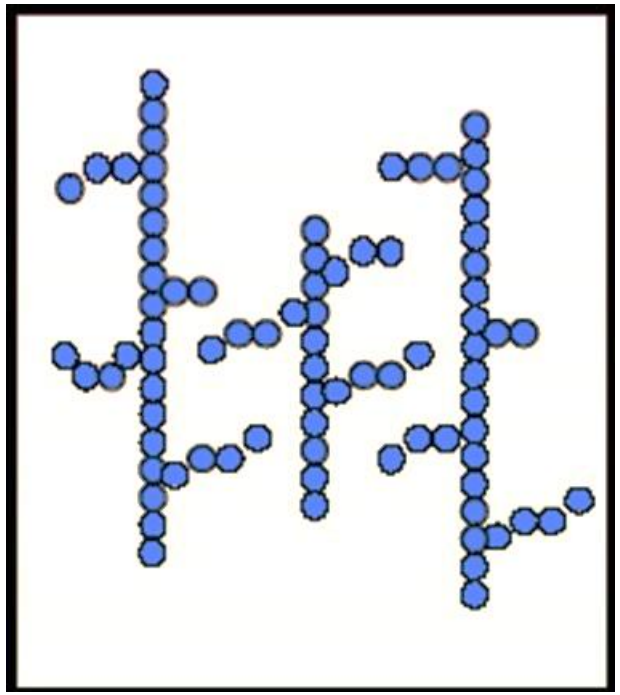
Low molecular weight (short polymer molecules)

Path of break is short (weak fiber)

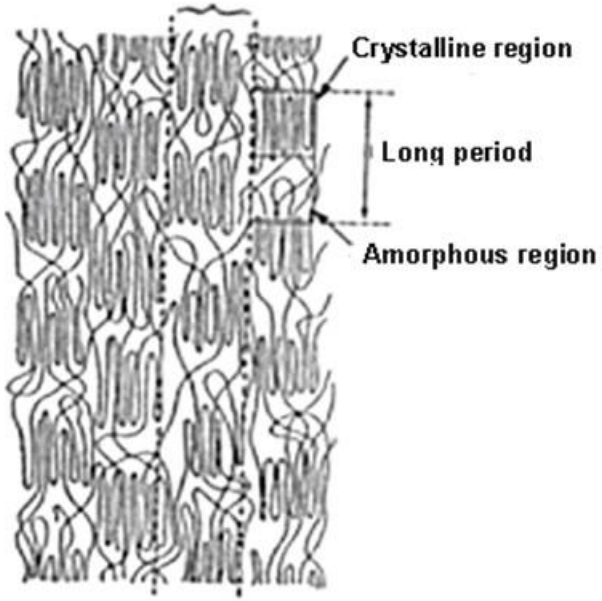
Linear Polymer



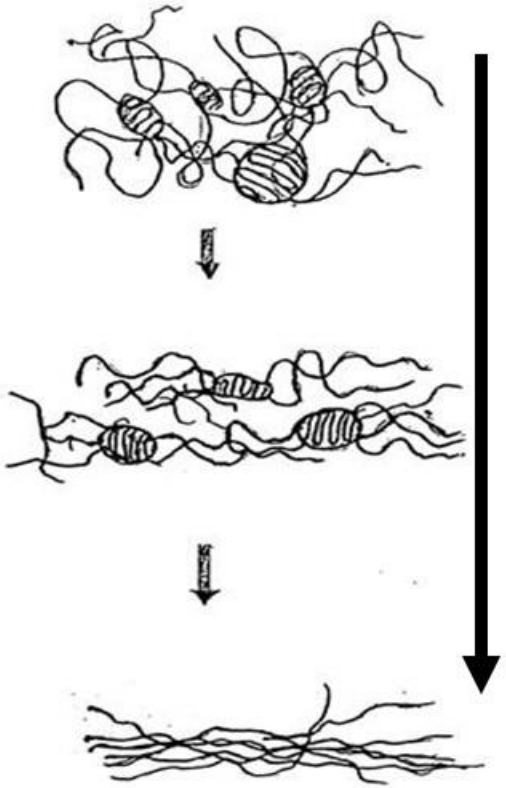
Non-linear Polymer



Linear polymers have a better chance to orient (crystallize) - fiber of satisfactory strength and desirable properties could be obtained



Organization of polymer chains in a crystalline polymer fiber



Orientation

(Alignment of polymer chains along the fiber axis)

Orientation also allows for greater intermolecular forces of attraction

Effect of increased orientation:

Increases: Strength, rigidity, gloss

Decreases: Elongation, chemical reactivity, dye absorption

More amorphous fibers are

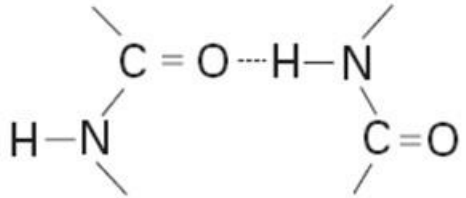
- More absorbent
- Weaker
- More easily degraded by chemicals
- More easily dyed
- Less rigid
- Less lustrous

More crystalline fibers are

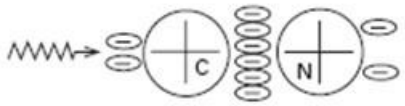
- Less absorbent
- Stronger
- Less easily degraded by chemicals
- Less easily dyed
- More rigid
- More lustrous

Intermolecular forces that provide cohesion between the polymer chains in solid state:

- Van der Waal's forces
- Hydrogen bonds
- Dipolar interactions



Hydrogen bonds between CO-NH groups



Electric dipoles in the acrylonitrile side group

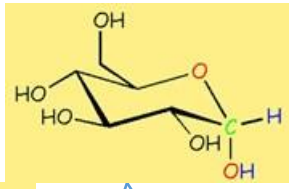
- High melting point is desirable since most textile fibers are subjected to some form of heat treatment either during processing or during day to day use.

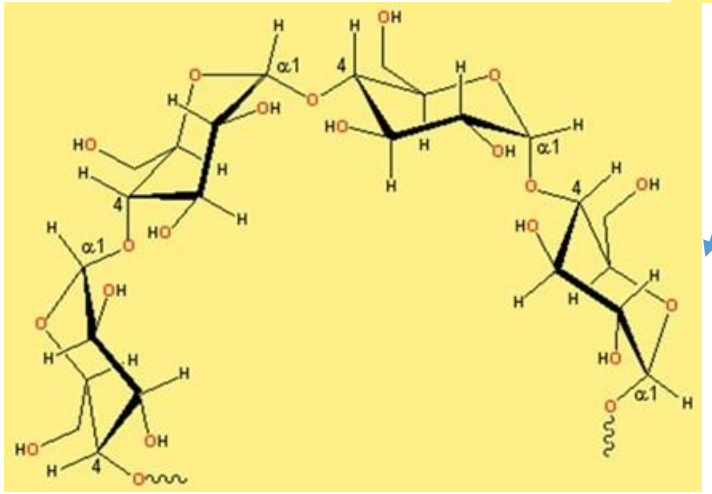
- High degree of crystallinity and strong intermolecular forces of interaction are required in the polymer to achieve high melting point.

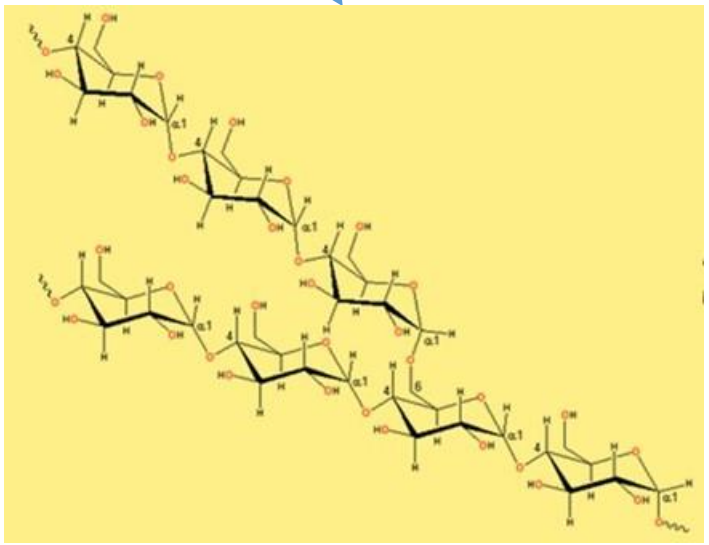
Starch vs. Cellulose

Starch

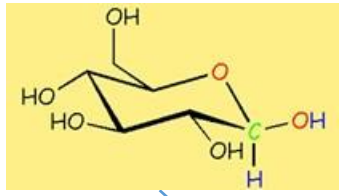
Glucose – α form



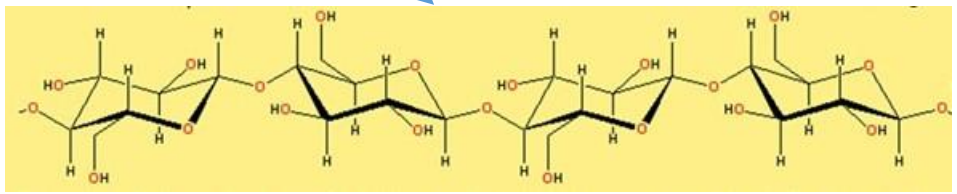




Cellulose



Glucose – β form



Order and disorder in fiber structure

Technique	Cotton	Wood pulp	Mercerised cotton	Regenerated cellulose
X-ray diffracton	27	40	49	65
Density	36	50	64	65
Deuteration	42	55	59	72
Moisture regain (sorption ratio)	42	49	62	77
Hailwood Horrobin	33	45	50	65
Non-freezing water	16	–	23	48
Acid hydrolysis	10	14	20	28
Alcoholysis	10	15	25	–
Periodate oxidation	8	8	10	20
Dinitrogen tetroxide oxidation	23–43	–	–	40–57
Formylation	21	31	35	63
Iodine sorption	13	27	32	52

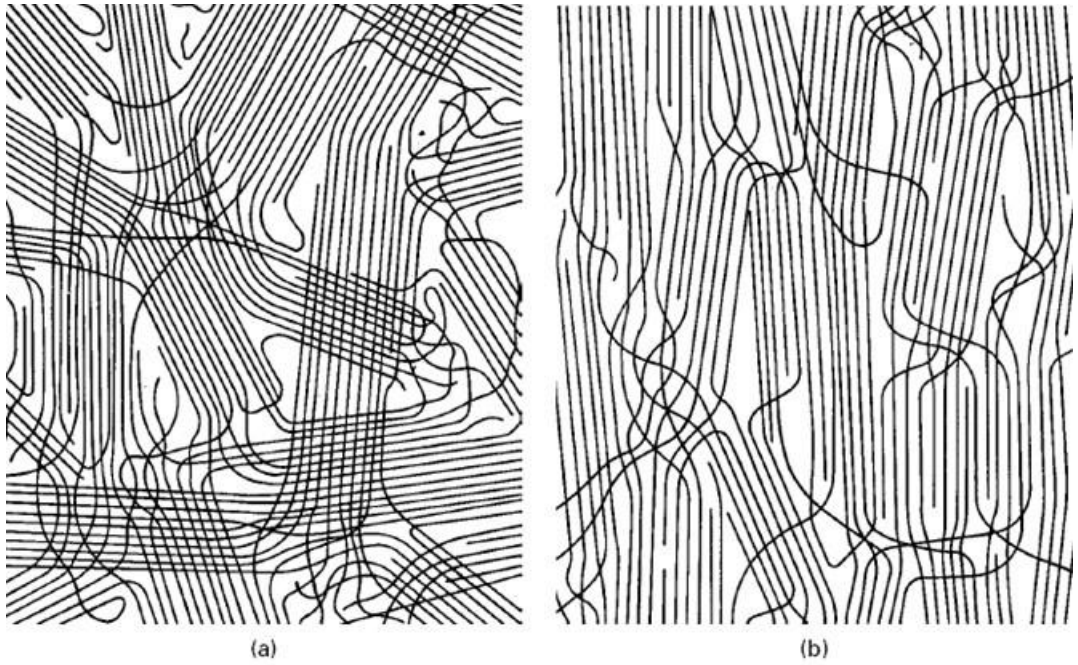
Percentage of disordered material in various celluloses

Order and disorder in fiber structure

Celulose	Accessibility	Cellulose	Accessibility
Bleached cotton	44	Kenaf	49
Mercerised cotton	66	Flax	50
Finely ground cotton	87	Cotton linters	50
Sulphite pulp	57	Ramie	53
Mercerised sulphite pulp	70	Rayon	78
Jute	48	Potato starch‡	97
		Birch xylan‡	99

Percentage accessibilities of celluloses measured by exchange of hydroxyl hydrogens for deuterium

Order and disorder in fiber structure



Fringed micelle structures (a) unoriented (undrawn) fiber (b) oriented (drawn) fiber

Parameters to give reasonable specification to fiber structure:

- Degree of order
- Degree of localization of order
- Length / width ratio of localized units
- Degree of orientation
- Size of localized units
- Molecular extent

- Degree of order

  Mean values of some correlation function relating the position of neighboring chains

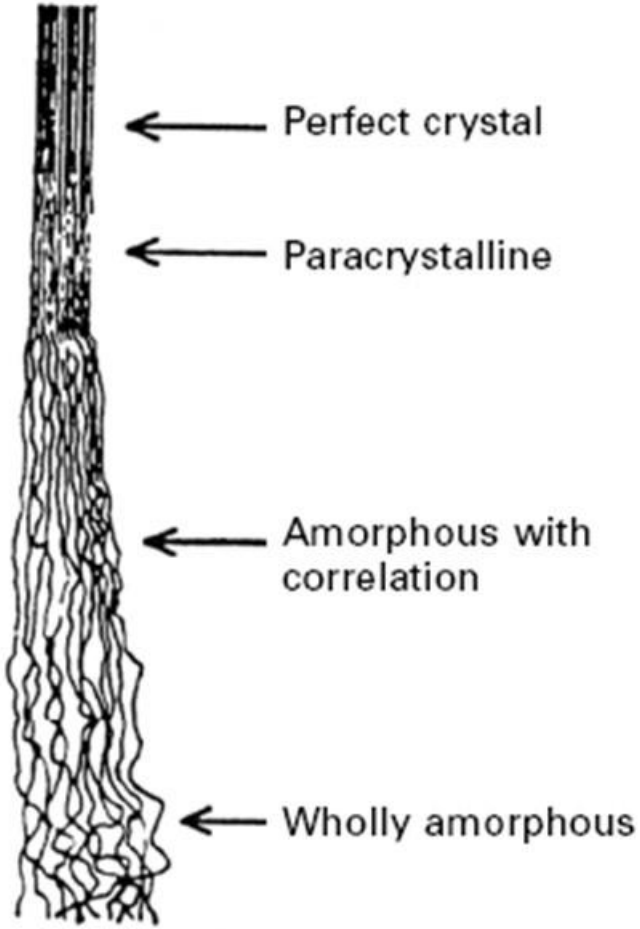
- Degree of localization of order

  Measure of the spread of degree of order taken over zones a few molecule wide

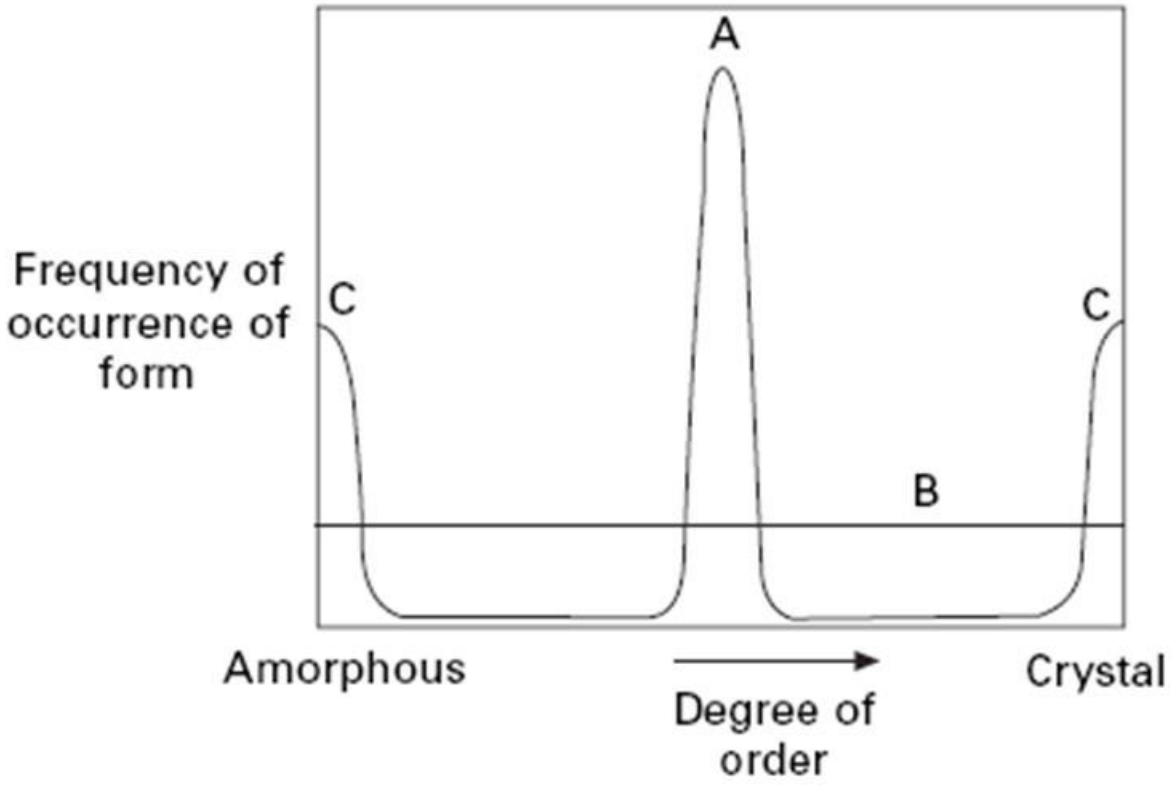
- Length / width ratio of localized units

  More straightforward parameter, ranging from infinity (for very long fibrils) to unity (for cubic micelles) to zero (for extensive flat sheets)

Order and disorder in fiber structure

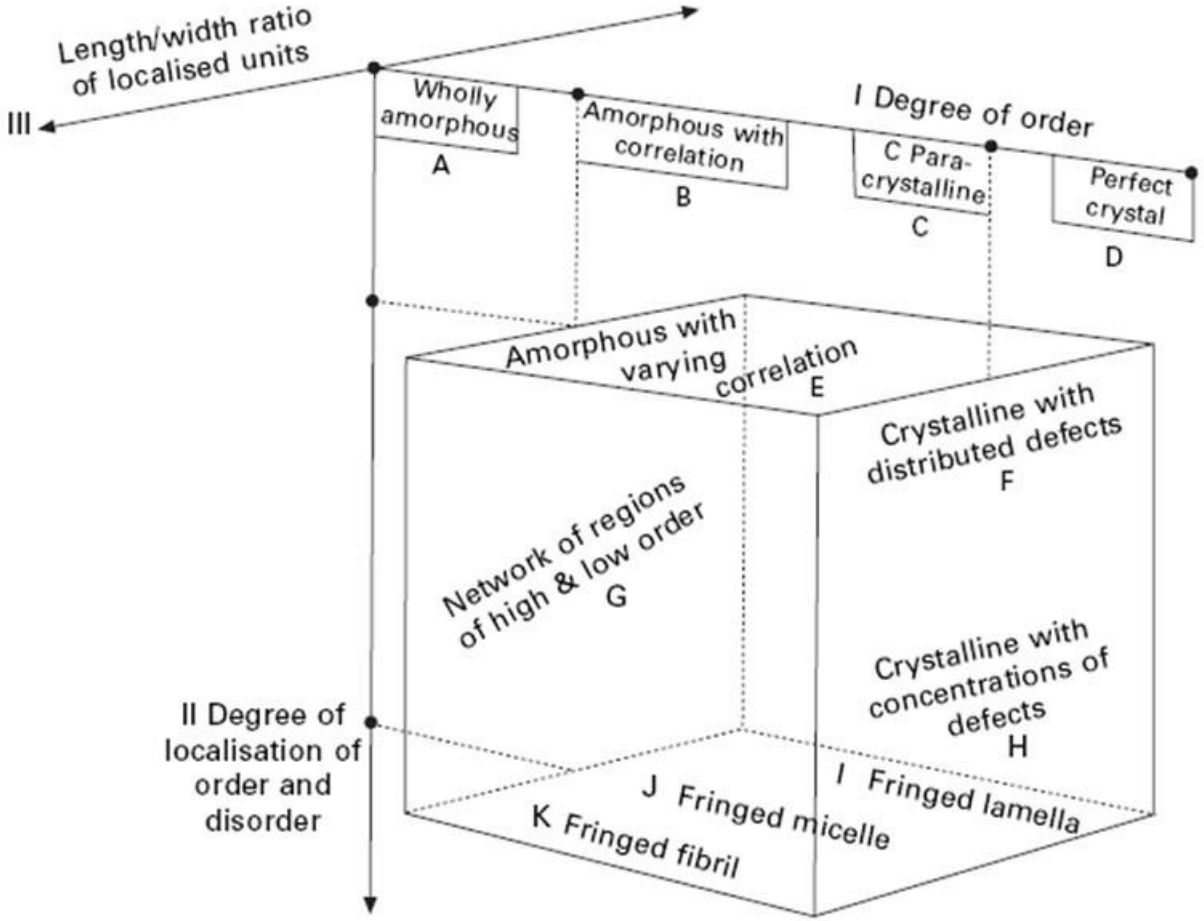


Range of degrees of order of packing of molecules in a fiber



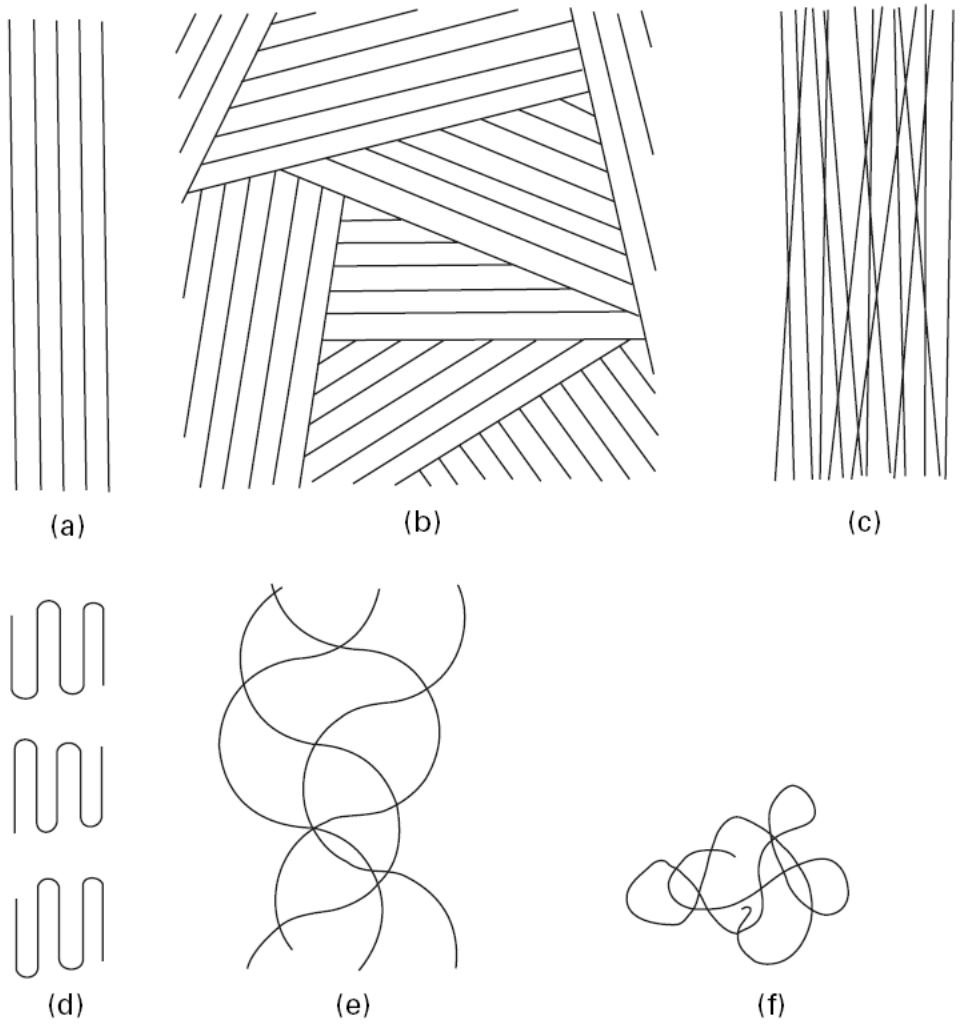
Three of many possible distributions of degree of order in a 50% crystalline fiber (A) uniform intermediate order (B) all degrees of order equally represented in different regions (C) mixture of highly ordered and highly disordered regions

Order and disorder in fiber structure



Schematic representation of fibre structure in terms of three major variables

Order, Orientation and Extent



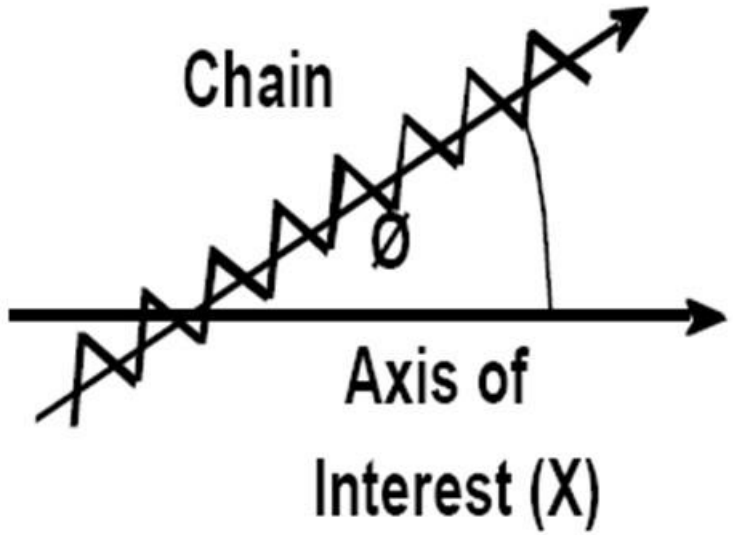
(a) Maximum order, orientation and extent
(b) Higher order, zero orientation
(c) Low order, high orientation
(d) High orientation, low extent
(e) Zero orientation, high extent
(f) Minimum order, orientation and extent.

Chain orientation along fiber axis

- All polymer properties are different when measured parallel to the chain axis direction versus perpendicular to that direction (covalent bonds vs. Van de Waals or other weak interchain bonding
- Processing can deliberately or incidentally align chains in specified directions
- Such alignment may results in the processed item having significantly different properties in different directions in the item - Anisotropic
- NOTE – chains may be aligned and yet be completely amorphous, aligned chains are not necessarily organized in a 3D crystalline array
- In order to relate properties to orientation, whether the sample is semi-crystalline or completely amorphous the “degree of order” in the sample needs to be quantified and visualized

Chain orientation – Herman's Factor

- Fibres are generally used such that they are loaded along the fibre axis – thus fiber processing operations are designed to more or less align polymer chains with fiber axis
- Orientation does not imply crystallinity. Polymers can be amorphous and yet oriented.
- Herman's orientation function (**f**) is simply a mathematical construction that allows us to describe the degree or extent of orientation of the chain axis relative to some other axis of interest.
- Herman's orientation function '**f**' has the properties that, relative to the direction of interest, if 'on average' the chain axis is:-
    - completely aligned **f** = 1
    - randomly oriented **f** = 0
    - perpendicular **f** = - 0.5

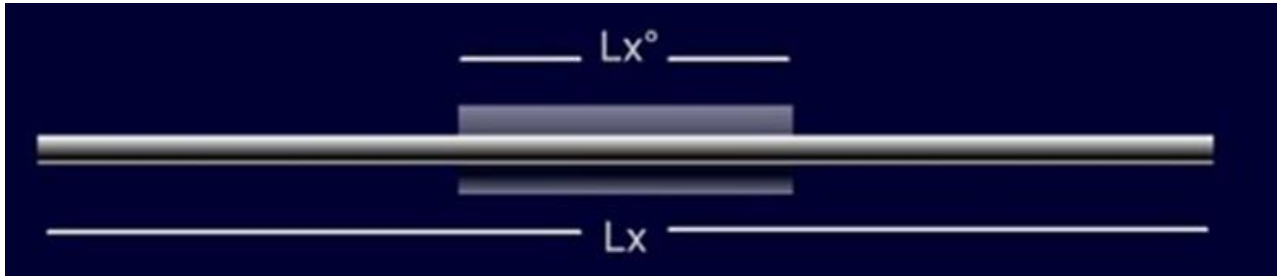


$$f = (3\{\overline{\cos}^2\emptyset\} - 1)/2$$

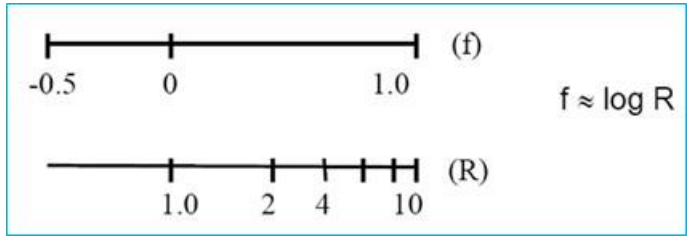
- Polymer chains within the fiber may be organized into crystalline and amorphous regions - the average angle between fiber axis and chain axis may not be same in these two regions
- "**f**" for chains in crystallites ($\mathbf{f_c}$) may be different from those in amorphous regions ($\mathbf{f_a}$)
- An orientation function can be used to estimate physical properties as a function of orientation and fractional crystallinity

Chain orientation – Herman's Factor

- A very efficient way to introduce significant chain orientation in a fiber is by cold drawing (in between T_m and T_g)
- If a sample draws uniformly and starts with an original length ($\mathbf{L_x°}$) and draws to $\mathbf{L_x}$ then Draw ratio (**R**) is defined as $\mathbf{L_x / L_x°}$



- If the original sample ($\mathbf{L_x°}$) contained unoriented chains (i.e. **f** = 0), then by the time this sample is drawn to ≈ 10 times its original length (i.e. $\mathbf{L_x} \approx$ 10 $\mathbf{L_x°}$, or **R ≈ 10**), chain orientation in the resulting sample is such that **f** ≈ 1 relative to the draw direction i.e. **f ≈ log R**)
- NOTE – valid for cold drawing only. Also remember that **f** = 1 is the highest possible orientation that can be produced. If **R** = 100 or **log R** = 2 and in theory **f ≈ log R =2**, still **f =** 1.



Fiber Fineness

Dimensions of fiber features (appx.)

10 cm	
	Fibre lengths
1 cm	
1 mm	Spacing of crimps in wool
0.1 mm	Spacing of convolutions in cotton
10 μm	Fibre diameters
1 μm (10^{-4} cm)	Major structural features
	Molecular length
0.1 μm	Laminae
10 nm	Micro-fibrils
	Crystalline and non-crystalline regions
1 nm	Molecular width
1 Å (10^{-8} cm)	Atoms: C,N,O / H

Fiber dimensions

	'Typical'	Approximate range
Linear density	**1 dtex**	to 20 dtex
Length	**1 cm**	staple fibres to 10 cm; filament to infinity
Density	**1 g/cm^3**	polymer fibres to 1.5 g/cm^3; others to 10 g/cm^3
Mass	1 µg	20 dtex, 10 cm, 1.5 g/cm^3 → 300 µg
Diameter	11.3 µm	20 dtex, 1 g/cm^3 → 50 µm
Aspect ratio	1000:1	to ~ 10 000:1 for staple → infinity for filament
Specific surface	355 m^2/kg	20 dtex, 1 g/cm^3 → 80 m^2/kg
Assembly	10^9 fibres/kg	
1 square metre at 100 g/m^2	10^8 fibres	
Fibre elements	10^{12} per kg	

tex = g/km dtex = decitex = g/10 km

Solid fibers of circular cross section

$$A = \pi r^2 = \pi \frac{D^2}{4}$$

$$c = A\rho = \frac{A}{v}$$

$$D = 2\left(\frac{c}{\pi\rho}\right)^{1/2}$$

$$P = 2\pi r = \pi D$$

For a length L, surface area = PL and volume = AL

$$S_v = P/A = 2/r = 4/D$$

$$S_m = \frac{P}{c} = \frac{2\pi r}{c} = \frac{\pi D}{c} = 2\left(\frac{\pi}{\rho c}\right)^{1/2}$$

A = **Cross-sectional area**

D = **Diameter**

c = **Linear Density**

ρ = **Density**

v = **Specific Volume**

P = **Perimeter**

S_v = **Specific Surface (on Volume Basis)**

S_m = **Specific Surface (on Mass Basis)**

Hollow Fibers

For hollow fibres of circular cross-section, denote the outer edge by a subscript [$_o$], the inner edge by [$_i$], and the wall by [$_w$]. With A for area and r for radius, we have:

$$A_o = \pi r_o^2$$

$$A_i = \pi r_i^2$$

$$A_w = A_o - A_i = \pi r_o^2 - \pi r_i^2$$

$$\text{Void percentage} = 100\left(\frac{A_i}{A_o}\right)\%$$

$$\text{Wall thickness} = (r_o - r_i)$$

Maturity (**θ**) is the ratio of cross-sectional area of the cell wall (***A_w***) to the area of a circle of same perimeter P (***A_0***) .
Note: ***A_0*** is the area of the fiber before collapse. ***I*** is the reciprocal of **θ**, called as immaturity ratio.

$$\theta = \frac{1}{I} = \frac{A_w}{A_o} = \frac{4\pi A_w}{P^2}$$

For the fully collapsed fibre, the total fibre area A equals the wall area A_w.

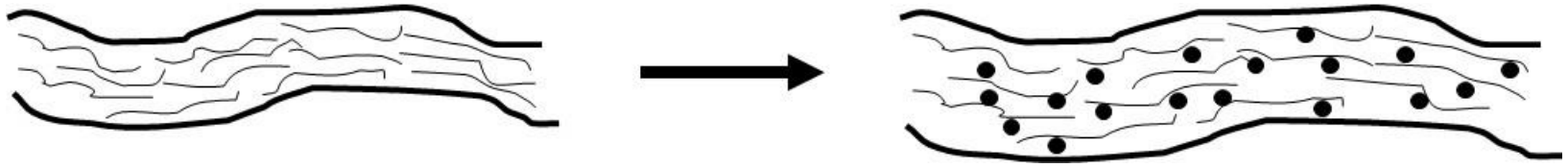
$$S = \frac{P}{A} = \left(\frac{4\pi}{A}\right)^{1/2} = 2\left(\frac{\pi\rho}{\theta c}\right)^{1/2}$$

$$\theta = \left(\frac{S^2}{4}\right)\left(\frac{c}{\pi\rho}\right)$$

Technical significance of fiber fineness

- Stiffness, handle and drape of fabric
- Torsional rigidity
- Reflection of light
- Adsorption of liquids and vapors
- Fiber cohesion and twist
- Yarn uniformity
- Shaped and hollow fibers
- Fiber end diameter

Moisture Absorption



Both axial and transverse swelling can take place

Significance

- Comfortable
- Easy to dye
- Affects dimensional stability
- Affects mechanical properties

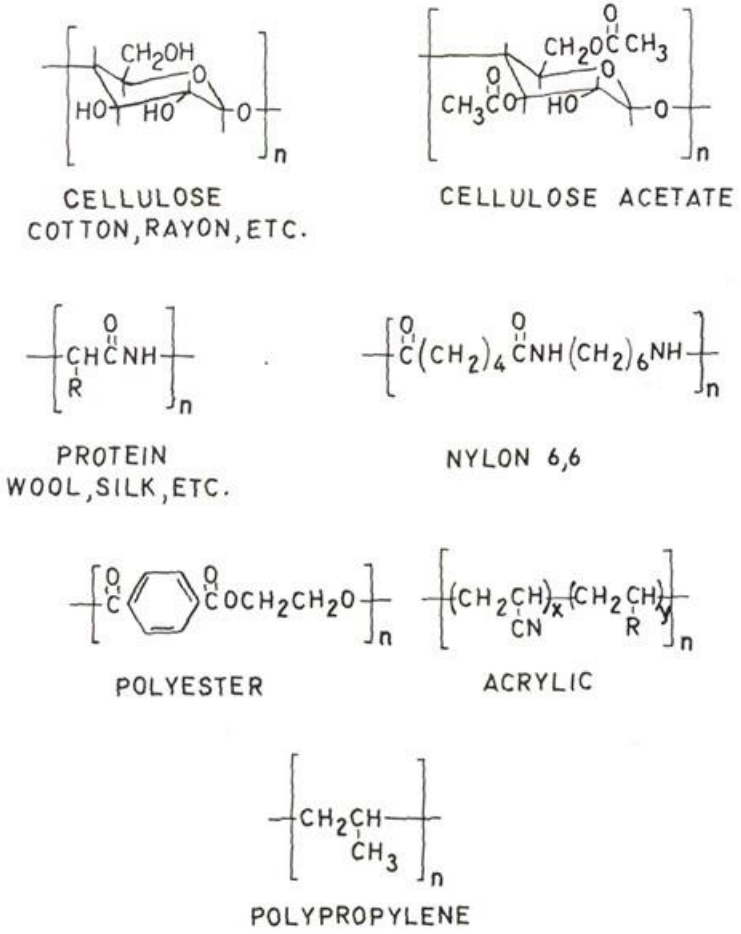
Primary Factors

- Availability of Hydrophilic Groups
- Amount of Amorphous Region

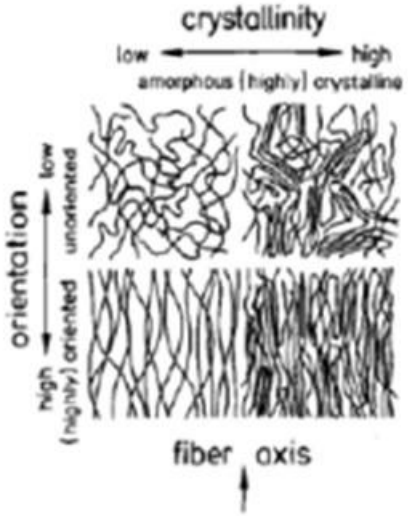
Secondary Factors

- Humidity
- Temperature

Availability of Hydrophilic Groups



Amorphous Content



	% Amorphous	Moisture Absorption (%) at 65% RH
Cotton	**~ 30**	**~ 10%**
Viscose	**~ 40**	**~ 12%**
Wool	**~ 70**	**~ 17%**
Silk	**~ 35**	**~ 11%**
Nylon	**~ 15**	**~ 4%**

<u>More amorphous the fiber:</u>

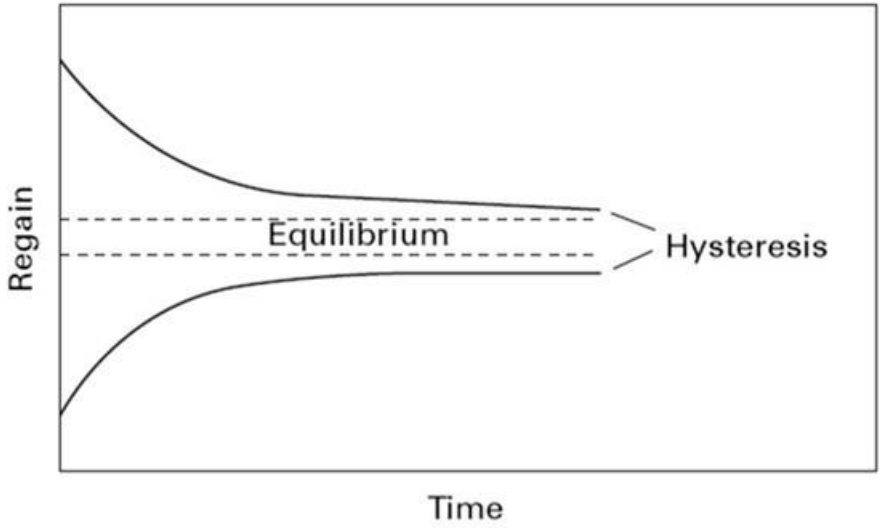
- more absorbent
- chemically less resistant
- easier to dye

Equilibrium Absorption of Water

Humidity

Absolute Humidity (***h***) = mass of water in unit volume of air

Relative Humidity = (***h*** / h_s) x 100 (where h_s is the absolute humidity of saturated air at same temperature



Approach to moisture equilibrium – hysteresis depending on whether sample is gaining or loosing weight

Moisture Regain (R) = (mass of absorbed water / mass of dry sample) × 100

Moisture Content (C) = (mass of absorbed water / mass of wet sample) × 100

$R = w/W \times 100$

$C = w/(w + W) \times 100 = R/(1 + R/100)$

Mass of absorbed water = w

Mass of dry sample = W

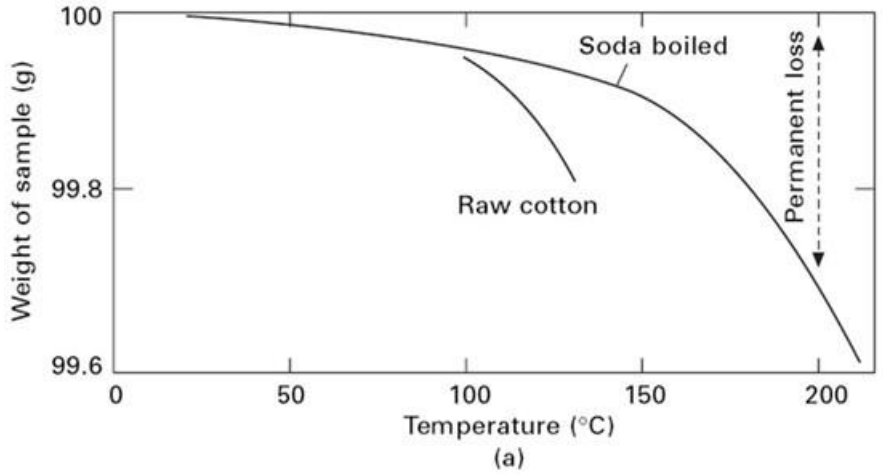
Equilibrium Absorption of Water

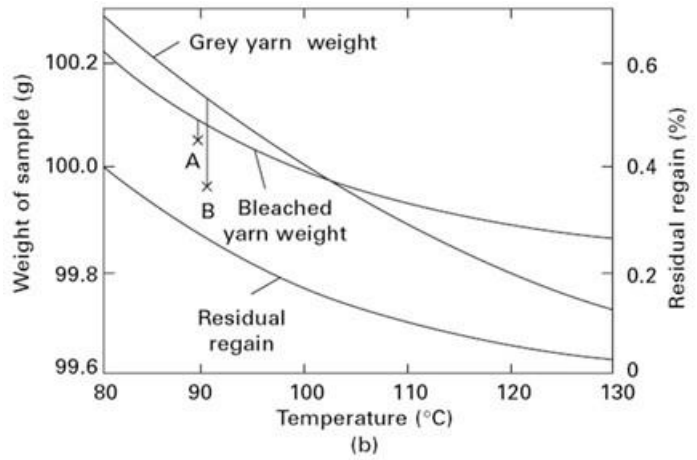
Residual Regain

Moisture that is left in equilibrium with sample at given temperature and humidity

Permanent loss

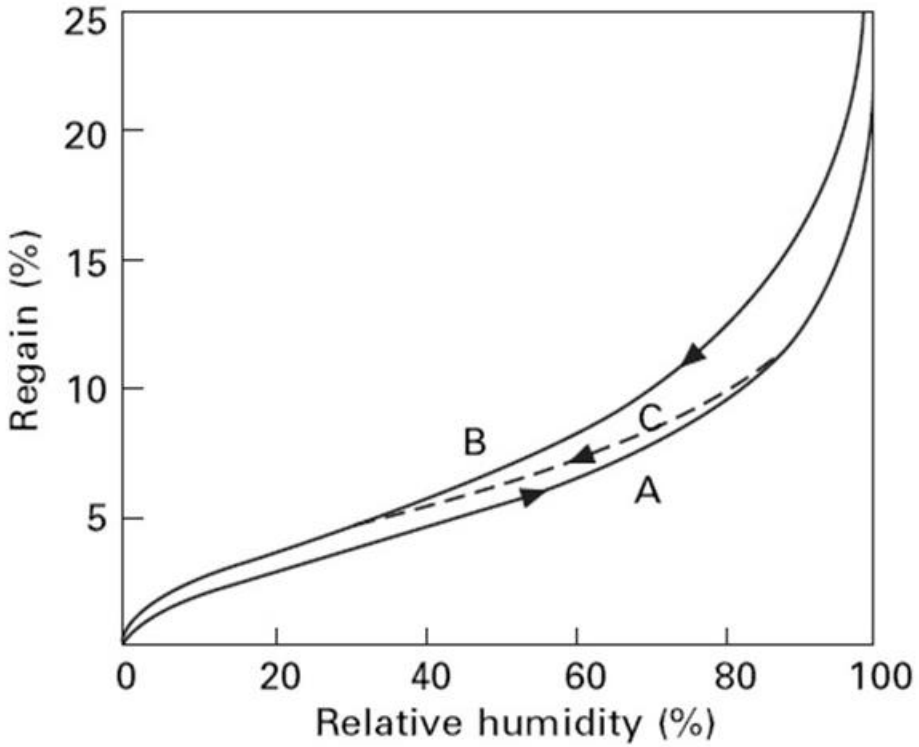
Loss in weight due to release of substances other than water e.g. oils and waxes when sample is heated



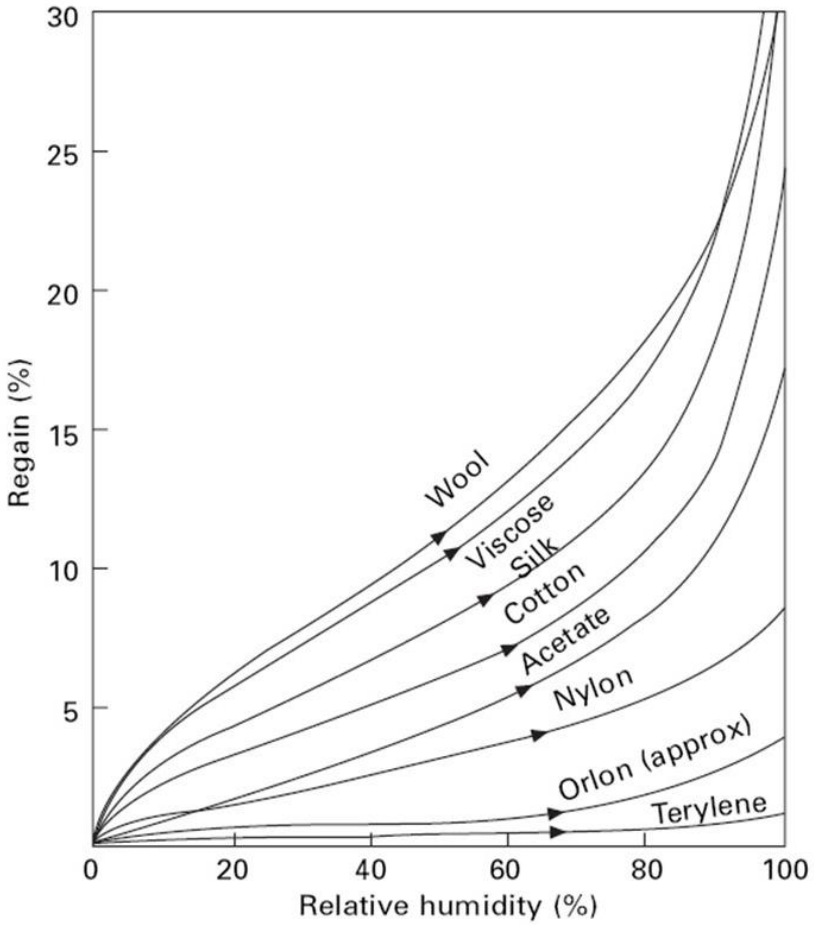


(a) Permanent loss on heating 100 g of dry cotton for 3 h *in vacuo*. (b) Change in weight of samples of cotton dried at water vapour pressure of 8 mm of mercury (1.07 kPa). Points A and B are for material dried at 130 °C, allowed to reabsorb water at room temperature, and then dried at 90 °C.

Regain and Relative Humidity

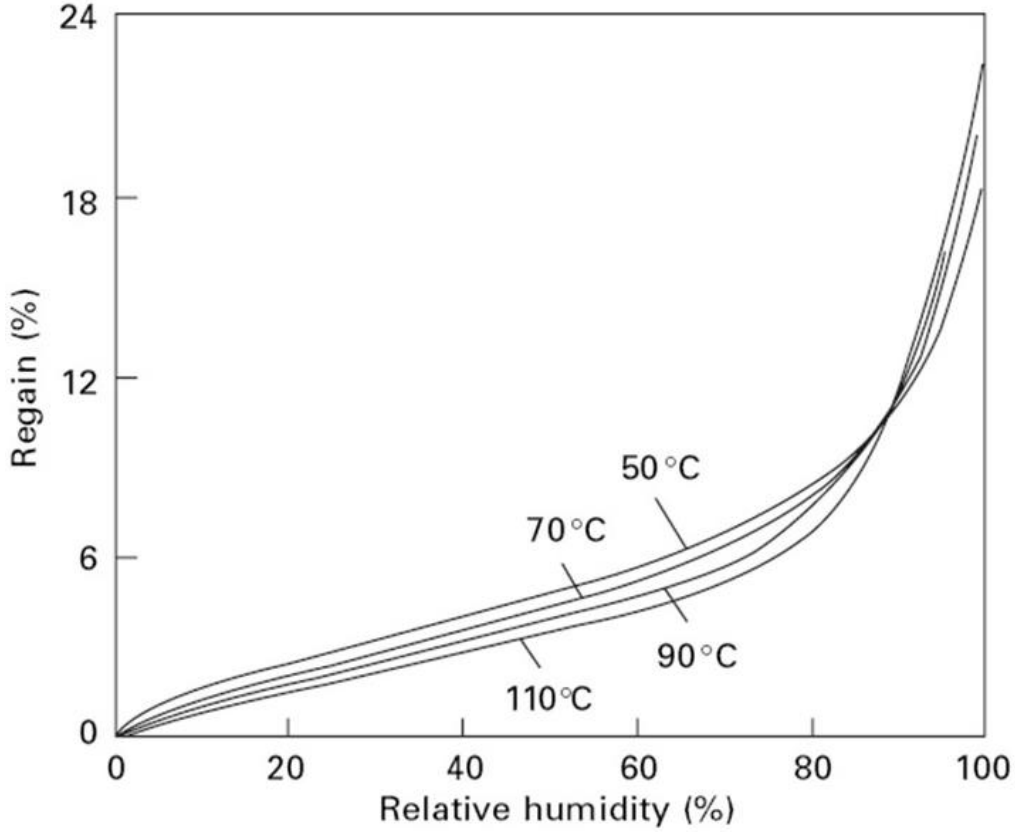


Typical curves of regain of soda boiled cotton against relative humidity (A) Absorption (B) Desorption (C) Intermediate

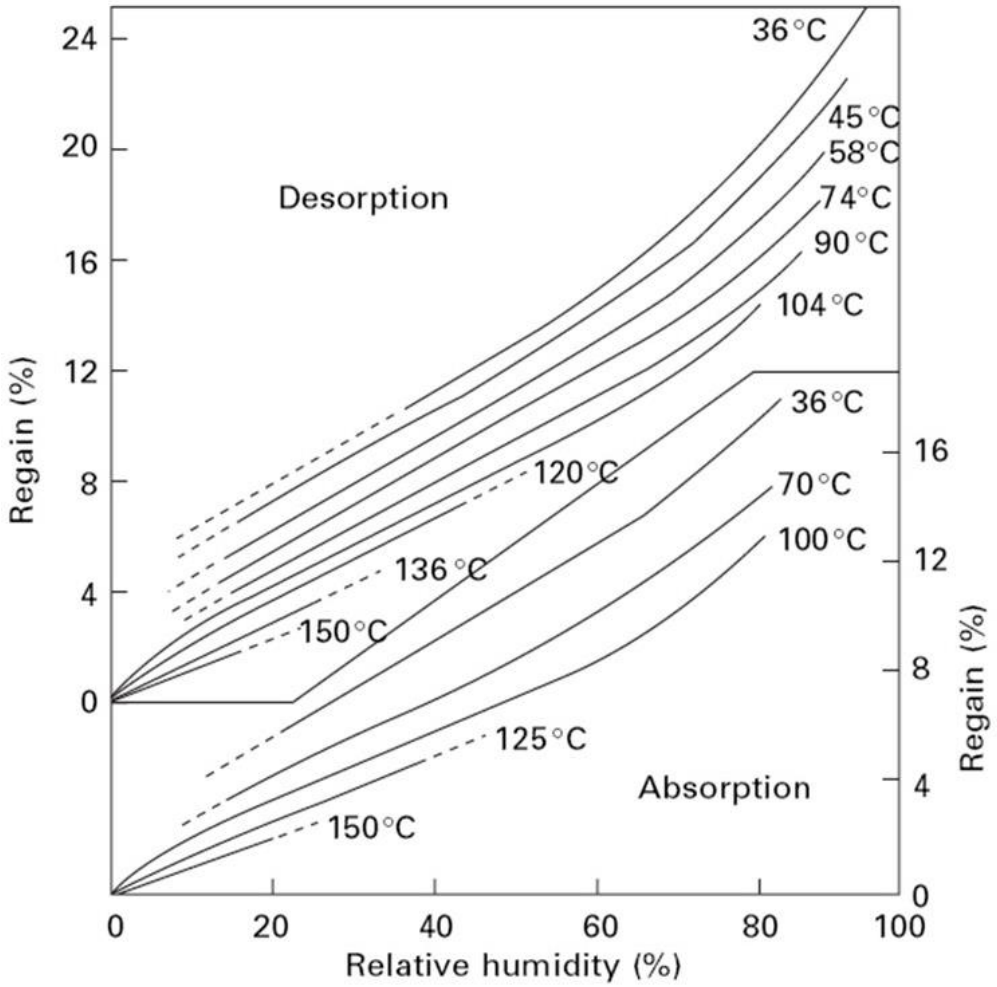


Regain vs. relative humidity for various fibers

Influence of Temperature



Effect of temperature on absorption of cotton



Effect of temperature on absorption of wool

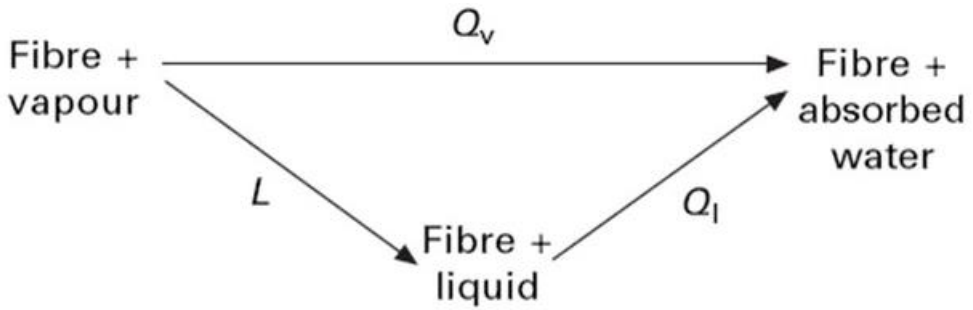
Influence of Stress

Effect of axial applied stress on moisture absorption at 75.5% r.h., 25 °C

Isotropic cellulose		Oriented cellulose		Horsehair	
Stress (MPa)	Increase in regain (%)	Stress (MPa)	Increase in regain (%)	Stress (MPa)	Increase in regain (%)
5.7	0.2	10.2	0.1	25.8	0.14
10.2	0.4	17.7	0.4	47.3	0.28
13.6	0.6	35.6	1.1		
27.4	1.5				
40.5	1.1				

Differential Heat of Sorption (***Q***) (or heat of absorption)

Heat evolved when 1 g of water is absorbed by an infinite mass of material at a given moisture regain (J/g of water absorbed)



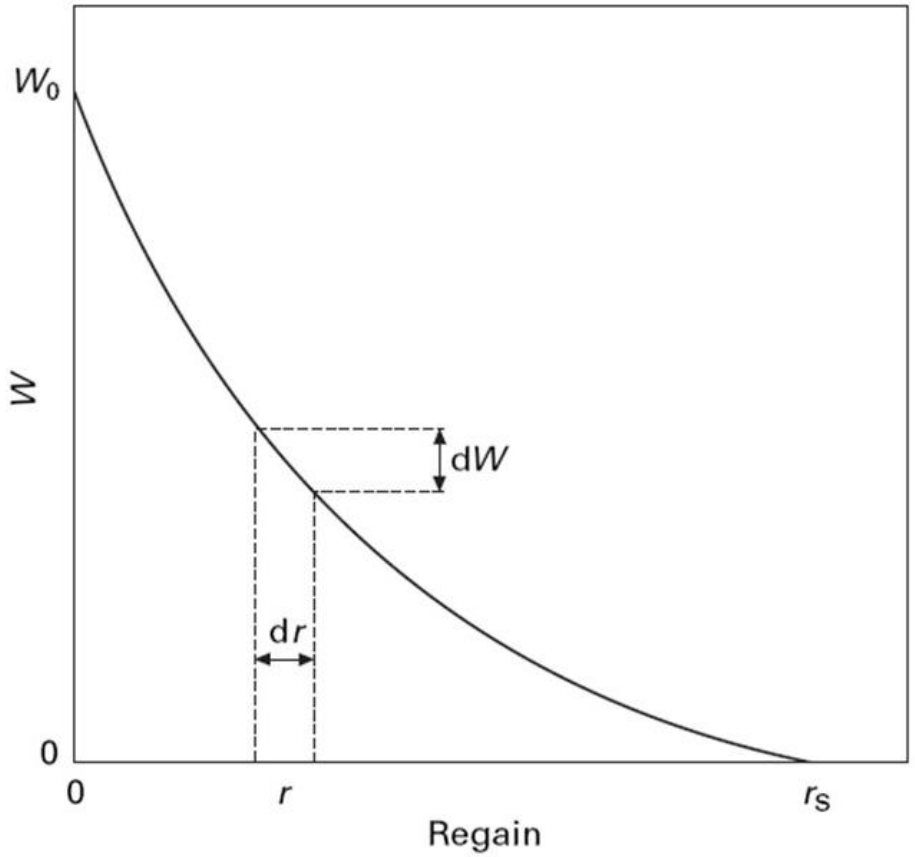
$$Q_v = Q_l + L$$

Where Q_v is heat of sorption from water vapor and Q_l is that from liquid water

L is latent heat of condensation of water in J/g at the temperature concerned

Integral heat of sorption(***W***) (or heat of wetting)

Heat evolved when a specimen of the material at a given regain, having a dry mass of 1 g, is completely wetted. (J/g of dry material)



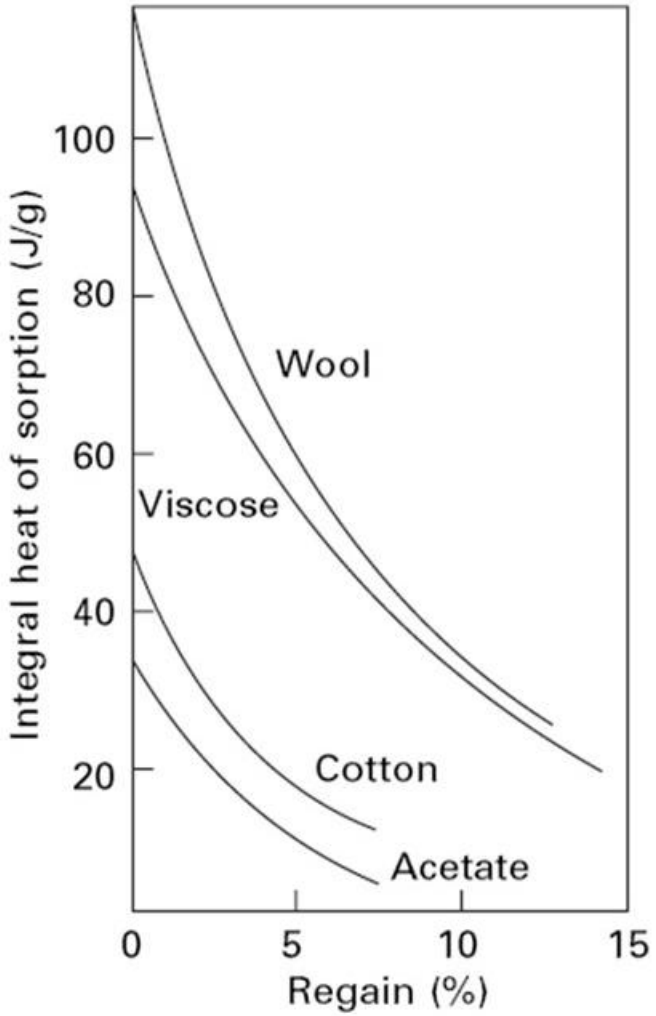
Variation of integral heat of sorption with regain

$$W = \int_{r}^{r_s} \frac{Q_1 \cdot \mathrm{d}r}{100}$$

$$Q_1 = -100 \frac{\mathrm{d}W}{\mathrm{d}r}$$

Heats of Sorption

Heats of wetting from zero regain W_0 (J/g)	
Cotton [1]	46
Mercerised cotton [1]	73
Flax [2]	55
Viscose rayon [2]	106
Secondary acetate [2]	34
Wool [3]	113
Silk [4]	69
Nylon [3]	31
Polyester (PET) 2.4 dtex [3]	5
Acrylic (PAN) [3]	7



Variation of integral heats of sorption of cotton, viscose rayon, secondary acetate [2] and wool [3] with regain.

Heats of Sorption

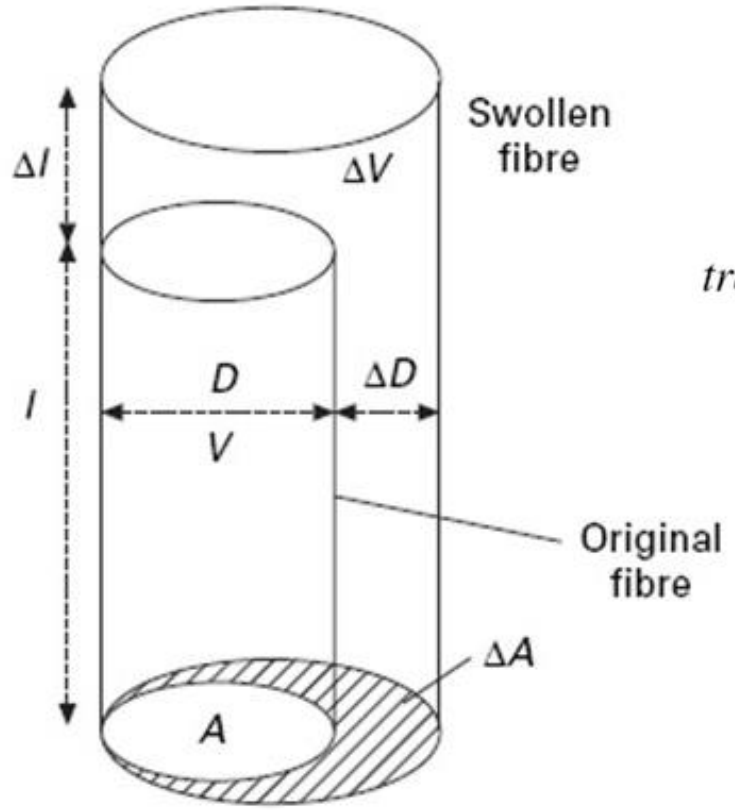
Differential heats of sorption Q_l (kJ/g)

Fibre	Relative humidity (%)					
	0	15	30	45	60	75
Cotton [2]	1.24	0.50	0.39	0.32	0.29	–
Mercerised cotton [1]	1.17	0.61	0.44	0.33	0.23	–
Viscose rayon [2]	1.17	0.55	0.46	0.39	0.32	0.24
Secondary acetate [2]	1.24	0.56	0.38	0.31	0.24	–
Wool [3]	1.34	0.75	0.55	0.42	–	–
Nylon [6]	1.05	0.75	0.55	0.42	–	–

Integral and differential heats of sorption

Fibre	At zero regain		At 65% r.h.
	W (kJ/g)	Q_l (kJ/g)	Q_l (kJ/g)
Cotton			
Bengals [2]	47.3	1.33	0.25
Texas [1]	46.1	1.19	0.20
Sea Island [2]	46.9	1.24	0.28
various sorts and methods [1, 7]	41–54	–	–
Viscose rayon			
continuous filament [2]	106	1.17	0.30
staple fibre [2]	97	1.22	0.27
various sorts and methods [1, 7]	84–105	–	–

Swelling



Changes in fibre dimensions on swelling.

transverse diameter swelling = fractional increase in diameter $= S_D = \frac{\Delta D}{D}$

transverse area swelling = fractional increase in area of cross-section $= S_A = \frac{\Delta A}{A}$

axial swelling = fractional increase in length $= S_l = \frac{\Delta l}{l}$

volume swelling = fractional increase in volume $= S_v = \frac{\Delta V}{V}$

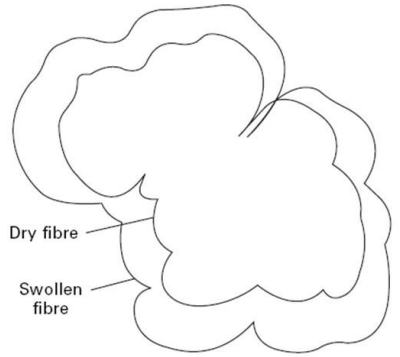
$$S_v = S_l + S_A + S_l S_A$$

$$S_A = 2S_D + S_D^2$$

Swelling

- **Axial Swelling**
- **Transverse Swelling**
- **Volume Swelling**

Outlines of cross-section of viscose rayon filament, dry and swollen in water.



If we consider a specimen of mass 1 g when dry, we have

$$V = \frac{1}{\rho_0}$$

$$V + \Delta V = \frac{1 + m}{\rho_s} = \frac{1 + r/100}{\rho_s}$$

where ρ_0 = density when dry, ρ_s = density when swollen, m = mass of water absorbed, and r = regain %. Hence:

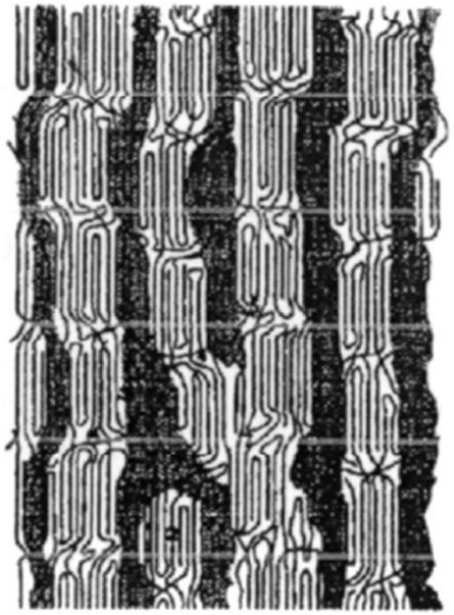
$$S_v = \frac{\Delta V}{V} = \frac{\left(\frac{1 + r/100}{\rho_s - 1/\rho_0}\right)}{1/\rho_0} = \frac{\rho_0}{\rho_s} \Big/ \left(\frac{1 + r}{100}\right) - 1$$

Thus the volume swelling may be found from measurements of density (by using the methods described in Section 5.2) and regain.

Swelling

Swelling of fibres in water. Values reported by various authors,

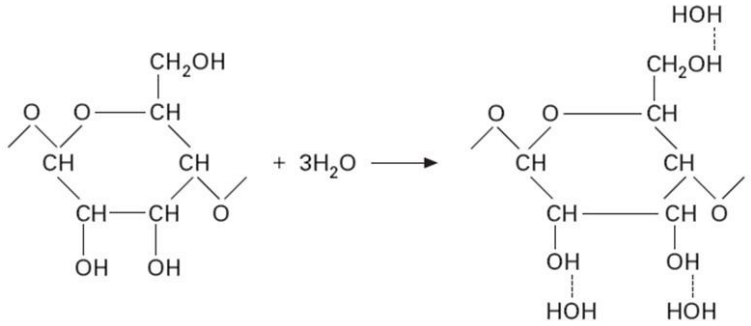
Fibre	Transverse swelling (%)		Axial swelling (%)	Volume swelling (%)
	Diameter	Area		
Cotton	20, 23, 7	40, 42, 21		
Mercerised cotton	17	46, 24	0.1	
Flax		47	0.1, 0.2	
Jute	20, 21	40		
Viscose rayon	25, 35, 52	50, 65, 67, 66, 113, 114	3.7, 4.8	109, 117, 115, 119, 123,126, 74, 122, 127
Acetate	9, 11, 14	6, 8	0.1, 0.3	
Wool	14, 8, 17	25, 26		36, 37, 41
Silk	16.5, 16.3, 18.7	19	1.6, 1.3	30, 32
Nylon	1.9, 2.6	1.6, 3.2	2.7, 2.9	8.1, 11.0



Micellar structure of nylon,

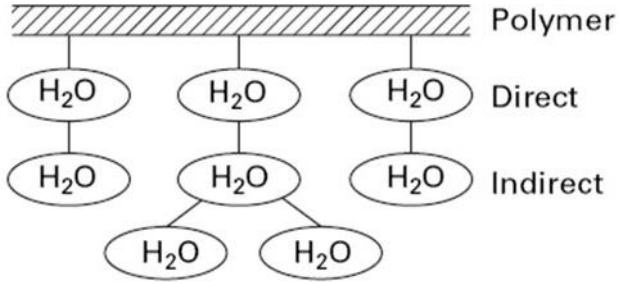
Theories of Moisture Absorption

(1) Effect of Hydrophilic Groups



Absorption of water by hydrogen bonding to hydroxyl groups in a cellulose molecules

(2) Directly and Indirectly Attached Water



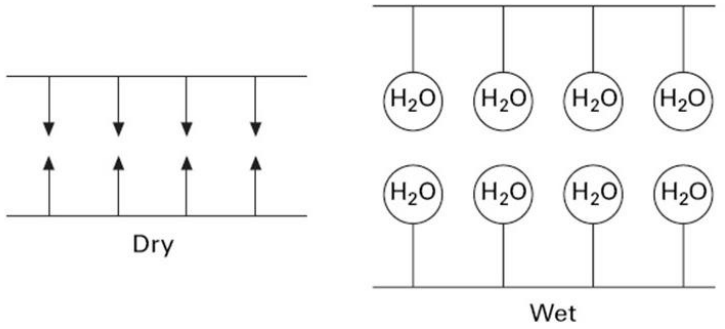
(3) Hysteresis – Molecular Explanation

DRY
structure with
many crosslinks

Crosslinks breaking
water attaching

Water coming off
crosslinks forming

WET
structure with
few crosslinks



(4) Absorption in Crystalline and Amorphous Regions

Theories of Moisture Absorption

Let ***C*** = total number of water molecules/absorption site

C_a = number of directly absorbed water molecules / absorption site

C_b = number of indirectly absorbed water molecules / absorption site

$$C = C_a + C_b \qquad \textit{(Eq. 1)}$$

If ***C*** increase by ***dC***, then fraction of molecules directly absorbed will be proportional to the number of unoccupied sites

$$\frac{dC_a}{dC} = q(1 - C_a) \qquad \textit{(Eq. 2)}$$

Where ***q*** is factor of proportionality. Upon integration we obtain

$$-\log_e (1 - C_a) = qC \qquad \textit{(Eq. 3)}$$

$$C_a = 1 - e^{-qC} \qquad \textit{(Eq. 4)}$$

Assuming ***q*** equal to 1 (by Peirce)

$$C_a = 1 - e^{-C} \qquad \textit{(Eq. 5)}$$

Substitution in Eq. 1 gives

$$C_b = C - 1 + e^{-C} \qquad \textit{(Eq. 6)}$$

We can express ***C*** in term of regain (***r***) of the material, since

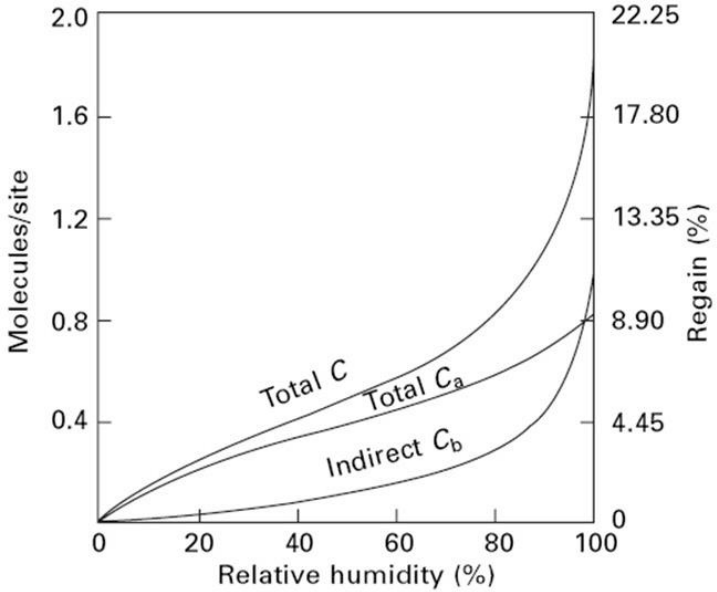
$$r = 100\left(\frac{\text{mass of absorbed water}}{\text{mass of material}}\right)\% = 100\,\frac{M_W C}{\gamma M_0} \qquad \textit{(Eq. 7)}$$

Where M_w = molecular weight of water

M_o= molecular weight per absorption site = 1/3 molecular weight of glucose residue* = 54

γ =total mass of material/mass of absorbing (amorphous) material

$$C = \frac{3\gamma r}{100} \qquad \textit{(Eq. 8)}$$



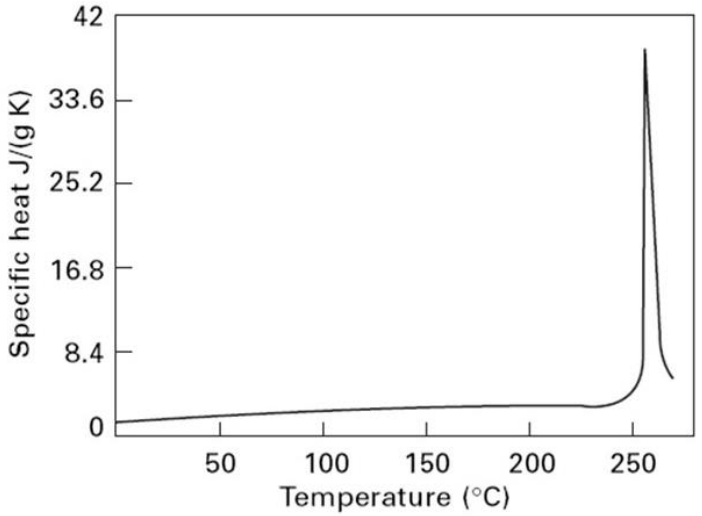
Division of regain of cotton between two phases on Peirce's Theory

Thermal Properties

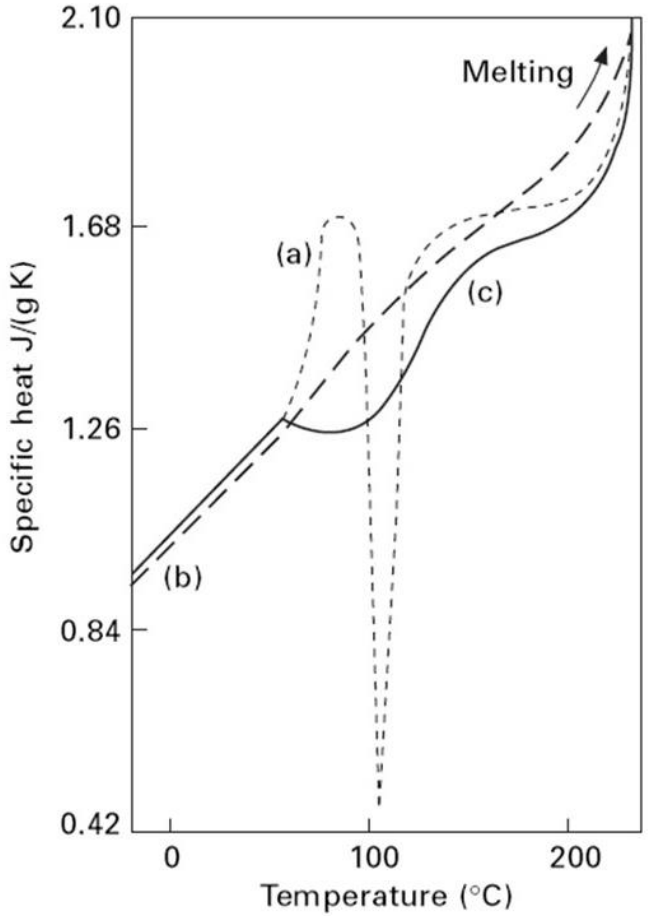
Specific Heat

Specific heat of dry fibres

Fibre	Specific heat J/(g K)
Cotton [1]	1.22–1.35
Rayon [1]	1.35–1.59
Wool [2]	1.36
Silk [2]	1.38
Nylon 6 [3]	1.43
Nylon 6.6 [1]	1.46
Polyester (PET) [1]	1.03
Asbestos [2]	1.05
Glass [2]	0.80



Specific heat of drawn nylon filament



Specific heat of *Dacron* polyester (a) undrawn; (b) annealed undrawn; (c) commercially drawn fibres.

The absorption of water, which as a liquid has a specific heat of 4.2 J/(g K), would be expected to increase the specific heat of fibres. For changes in temperature at constant regain, a simple mixture law would give the relation:

$$\text{mixture specific heat} = C' = \frac{C_0 + 4.2r}{1 + r}$$

where C_0 = specific heat when dry and r = fractional regain.

Thermal Conductivity

Thermal conductivity of polymers [1, 12]

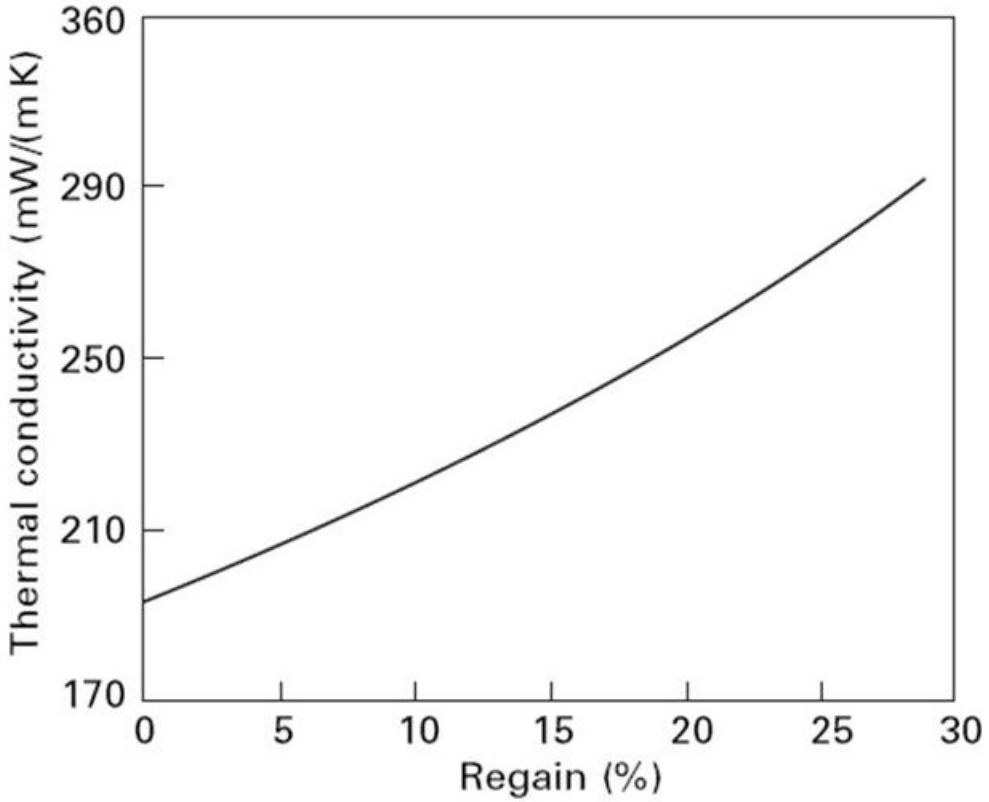
	Thermal conductivity (mW/(m K))
Cellulose acetate	230
Nylon	250
Polyester (PET)	140
Polyethylene	340
Polypropylene	120
Polyvinyl chloride (PVC)	160

Thermal conductivity of pads of fibres with a bulk density of 0.5 g/cm^3 [12, 13]

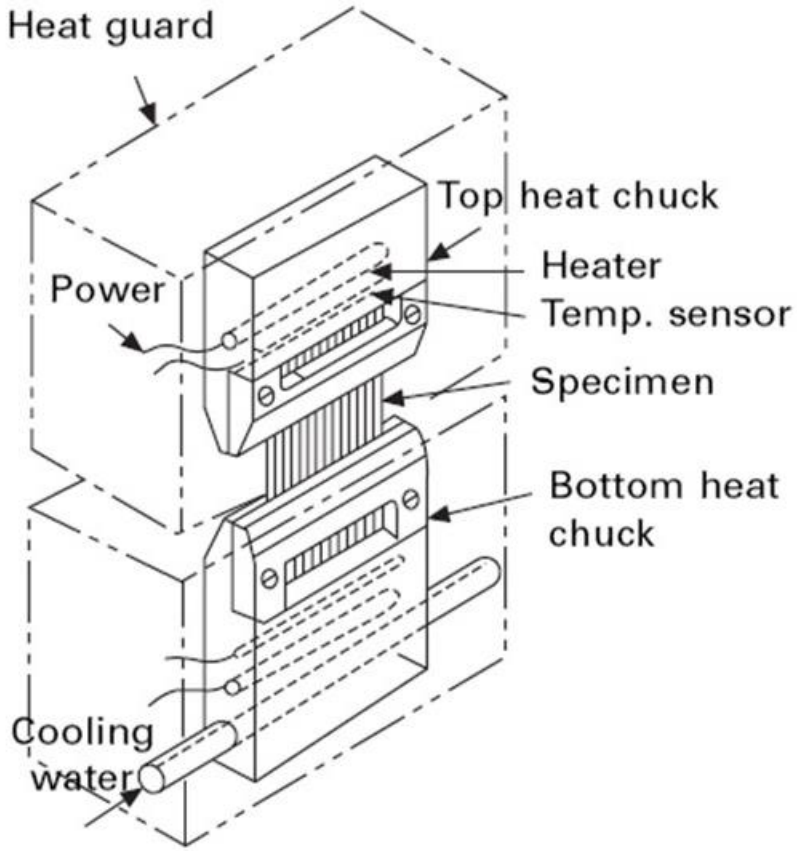
Fibre	Thermal conductivity (mW/(m K))
Cotton	71
Wool	54
Silk	50

Note: Still air has a thermal conductivity of 25 mW/(m K)

Thermal Conductivity



Variation of thermal conductivity of horn with moisture regain



Thermal conductivity measurement units:

The conductivity K_L is given by:

$$K_L = \frac{qL}{A\Delta T}$$

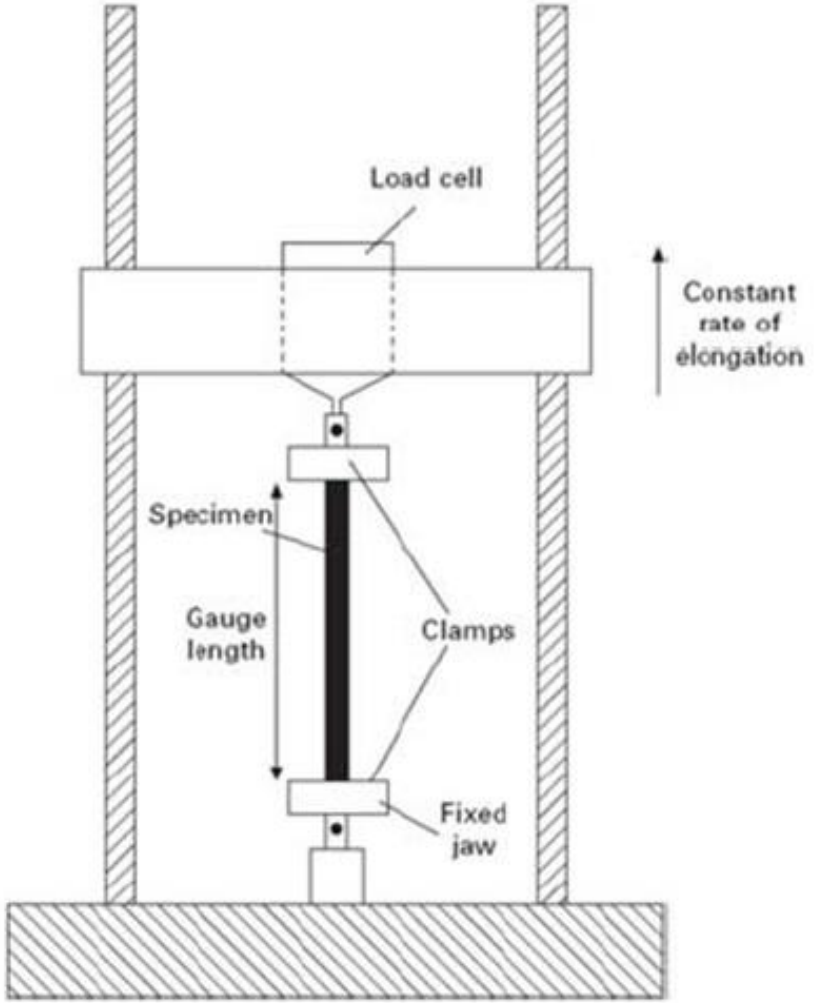
where q = heat flow rate, L = specimen length,

A = total area of fibre cross-sections

and ΔT = temperature difference between ends.

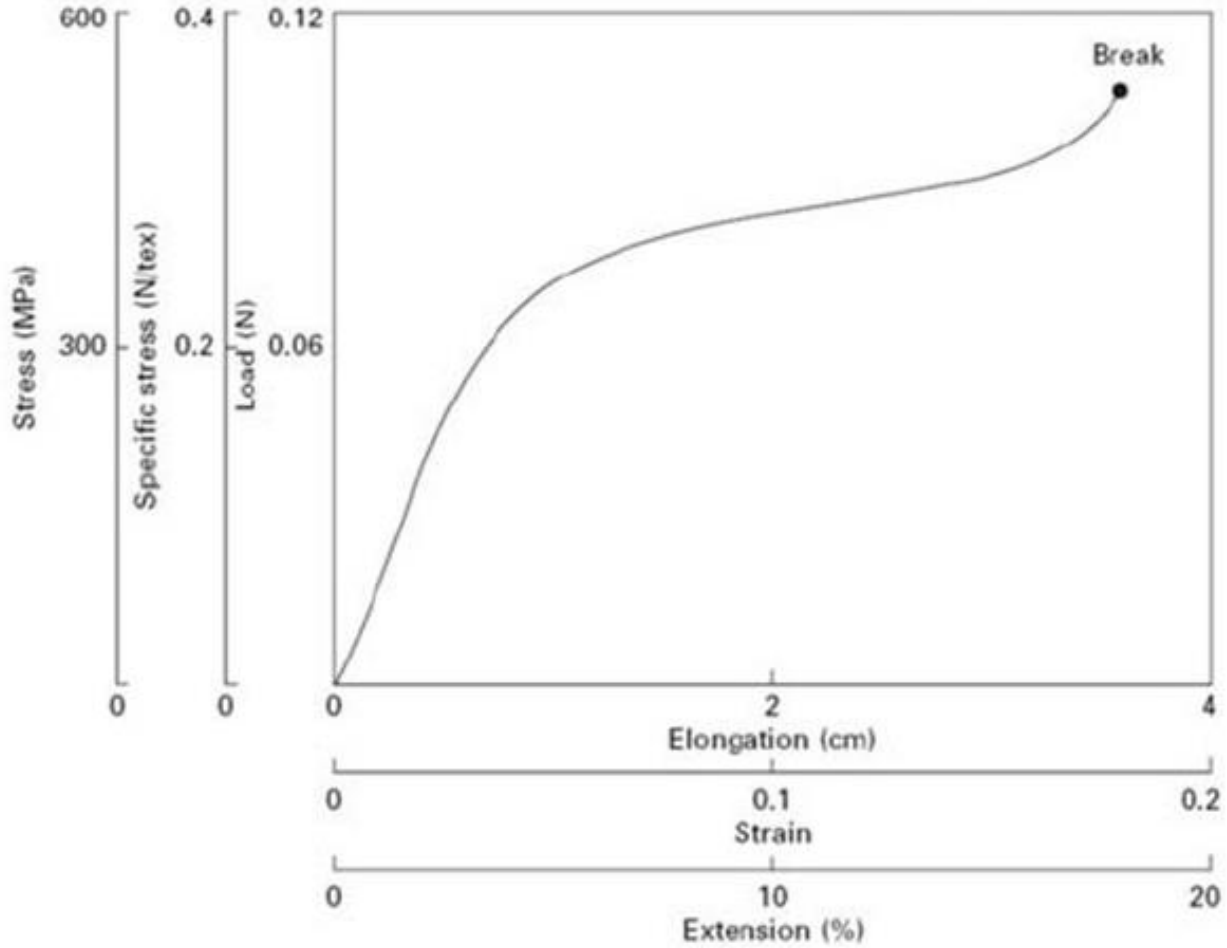
Mechanical Properties

- Why Tensile?
- Factors determining results of tensile experiments
  - Material and its condition
  - Arrangement and dimensions of specimen
  - Nature and timing of the test



Instron tester

Tensile Properties of Fibers

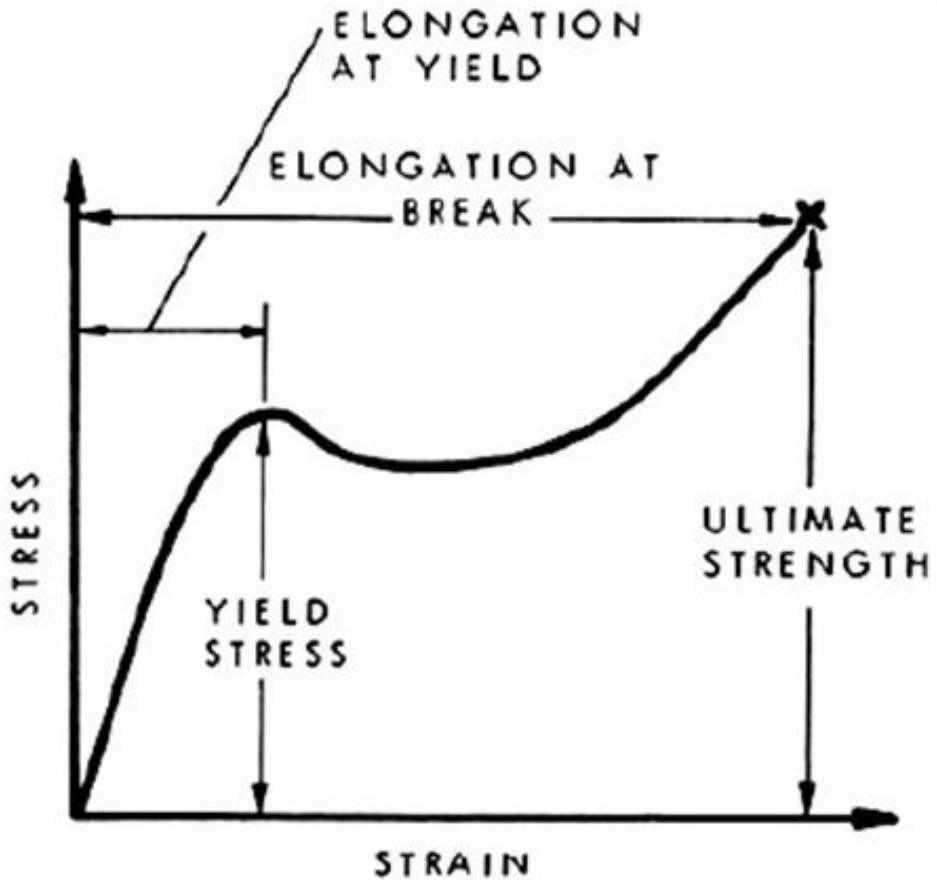


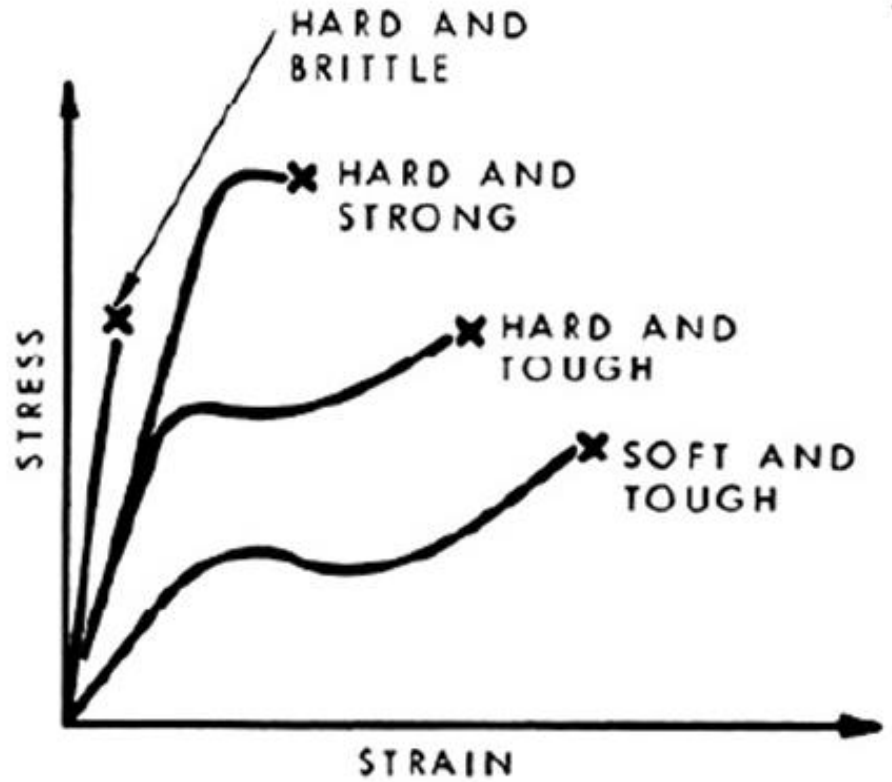
$$\text{stress} = \frac{\text{load}}{\text{area of cross-section}}$$

$$\text{specific stress} = \frac{\text{load}}{\text{linear density}}$$

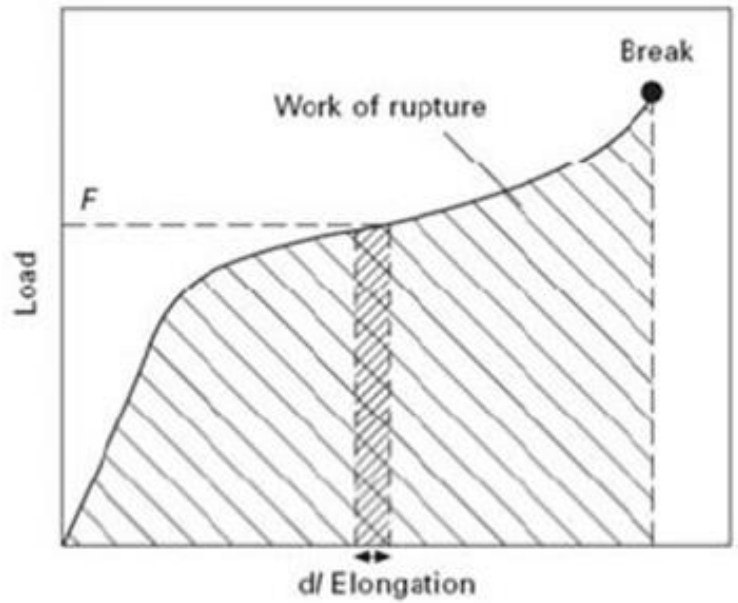
$$\text{tensile strain} = \frac{\text{elongation}}{\text{initial length}}$$

- **Modulus**
  - Slope of stress-strain curve at the origin (after removal of any crimp)
- **Strength at Break (Tenacity)**
  - Force per unit linear density required to break a fiber
  - Expressed in g/d or g/tex (N/d or N/tex)
- **Elongation at Break**
  - Amount of stretch necessary to break a fiber
- **Elasticity**
  - Ability to recover after being deformed


ELONGATION AT YIELD
ELONGATION AT BREAK
STRESS
YIELD STRESS
ULTIMATE STRENGTH
STRAIN


HARD AND BRITTLE
HARD AND STRONG
HARD AND TOUGH
SOFT AND TOUGH
STRESS
STRAIN

Work of Rupture

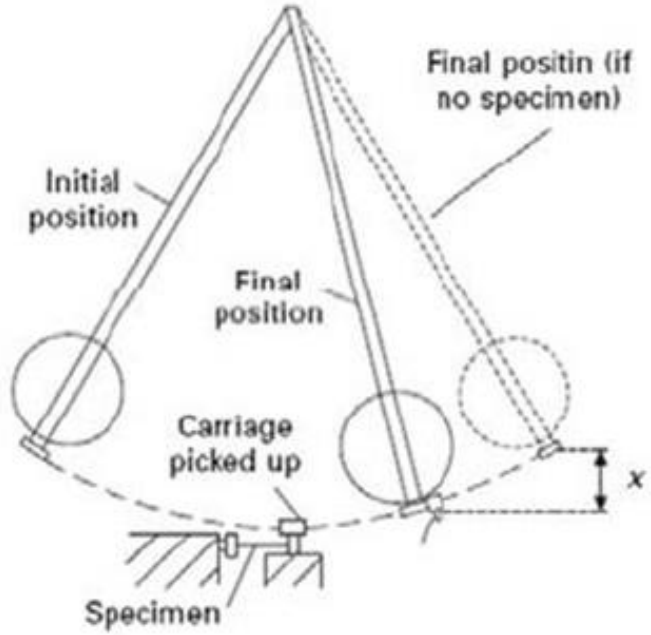


work done = force × displacement = $F \cdot dl$

total work done in breaking the fibre = work of rupture

$$= \int_0^{\text{break}} F \cdot dl$$

$$\text{specific work of rupture} = \frac{\text{work of rupture}}{\text{linear density} \times \text{initial length}}$$



Ballistic Tester

work of rupture = loss of potential energy = $M\ g\ x$

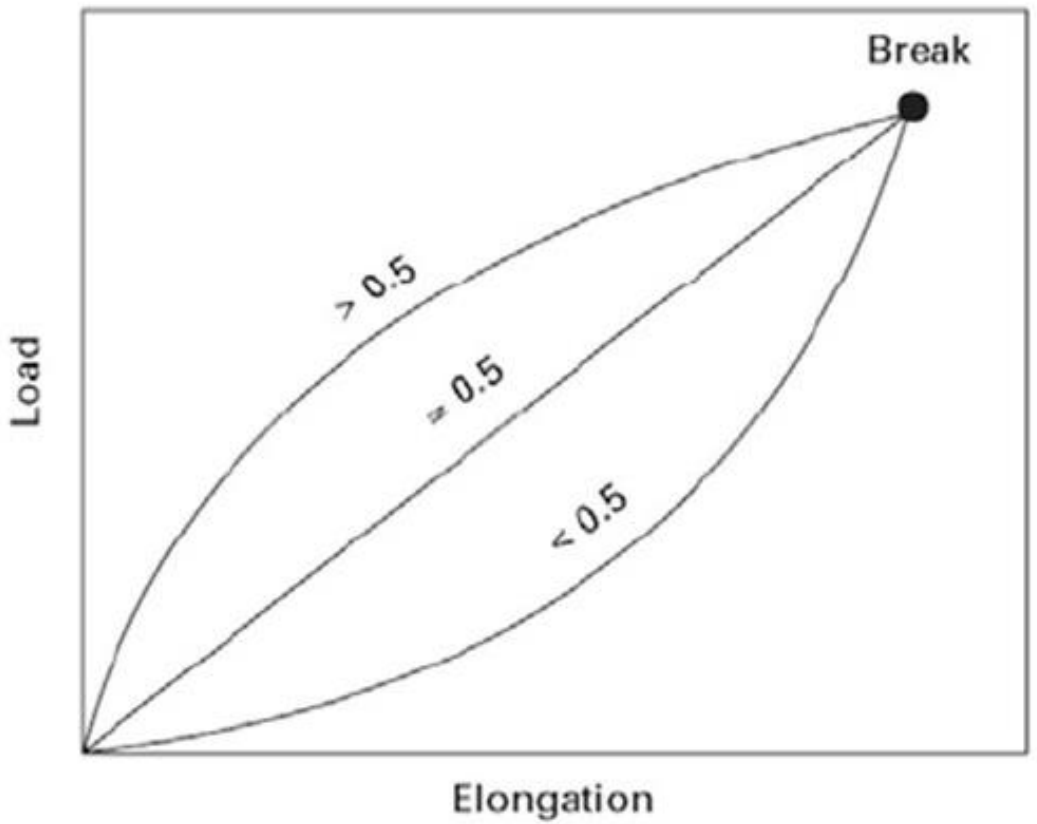
where M = mass of pendulum

x = difference in height of final positions of pendulum, with and without the specimen.

If the fiber obeyed Hooke's law, the load-elongation curve would be a straight line and the work of rupture would be given by:

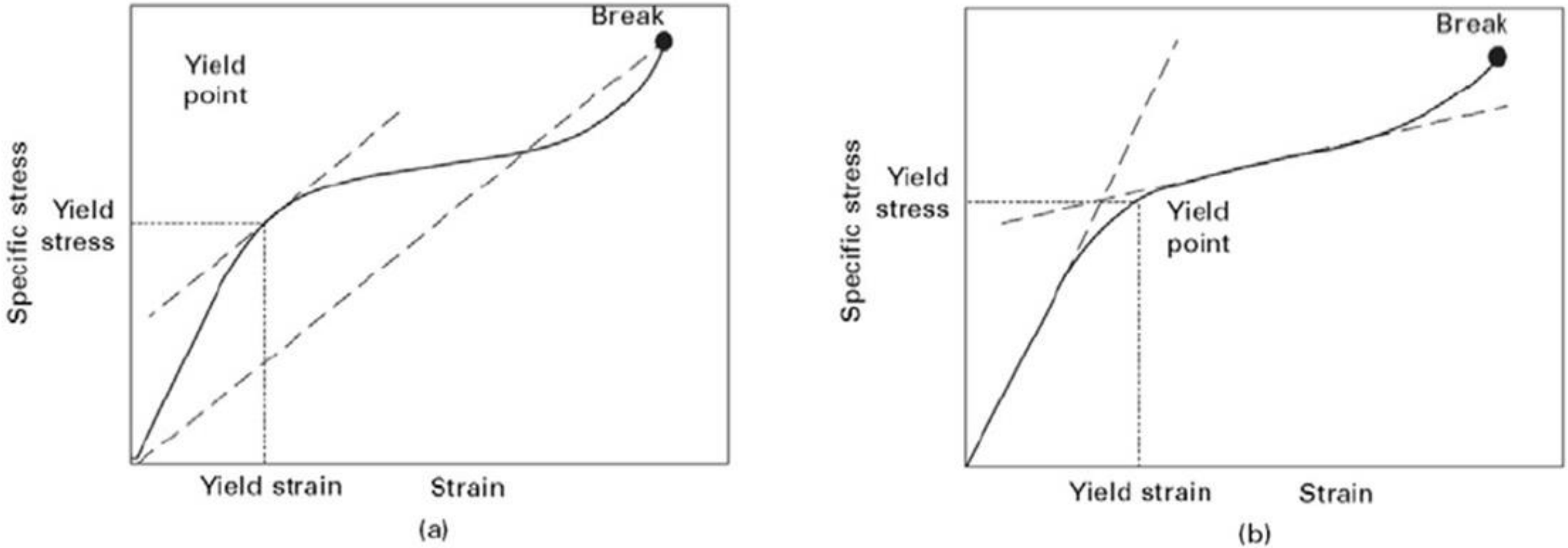
$$\text{work of rupture} = {}^{1}/_{2}\ (\text{breaking load} \times \text{breaking elongation})$$

$$\text{work factor} = \frac{\text{work of rupture}}{\text{breaking load} \times \text{breaking elongation}}$$



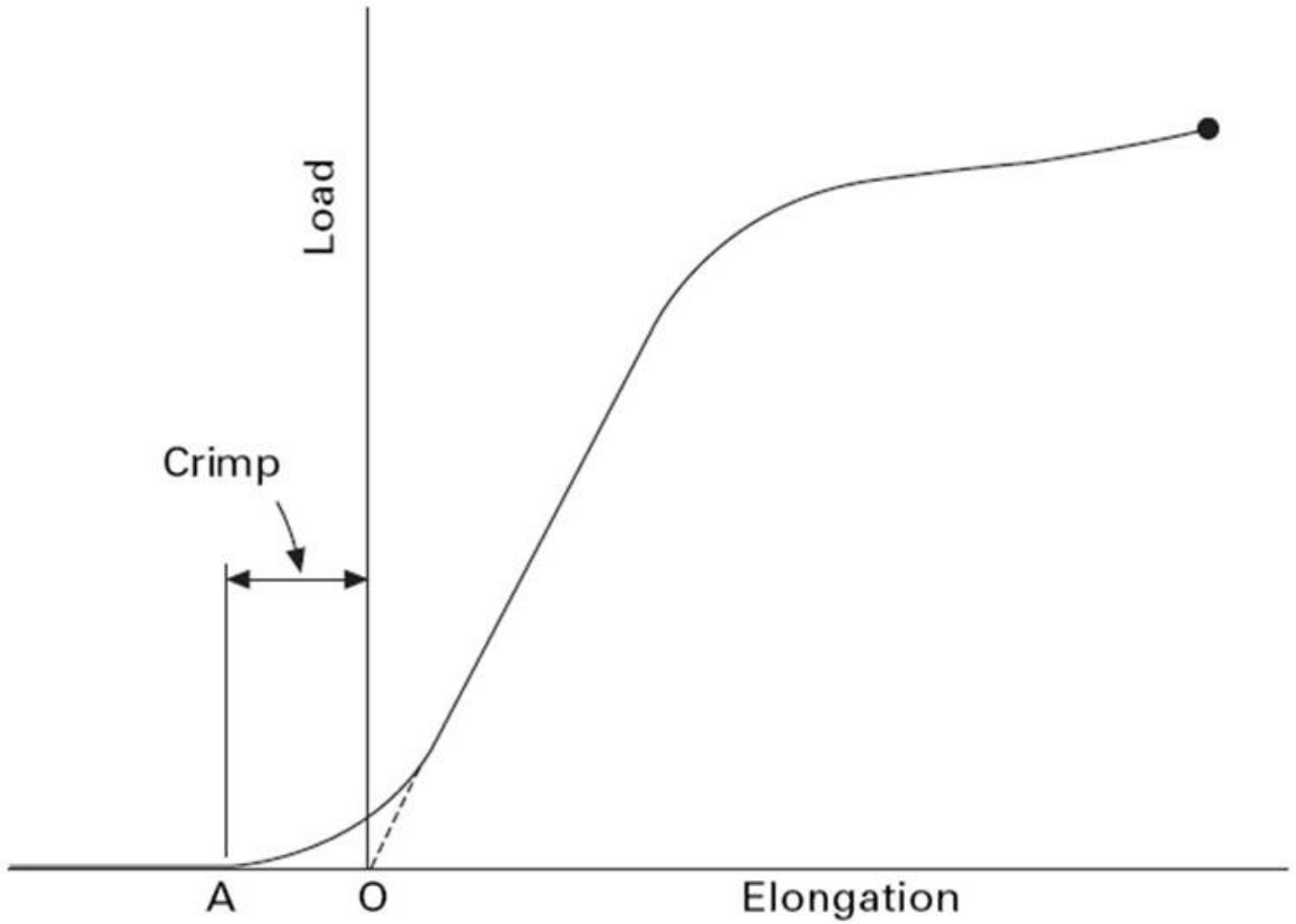
work factor

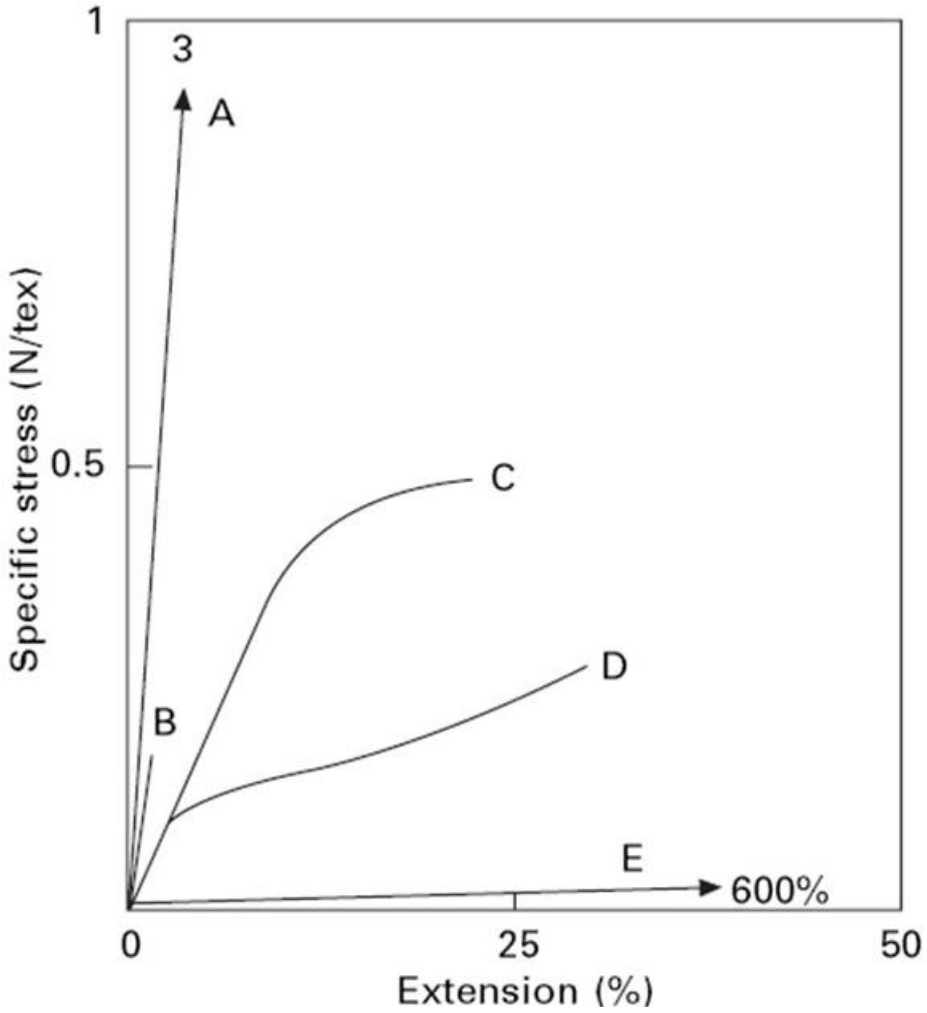
Yield Point



Yield point: (a) Meredith's construction; (b) Coplan's construction

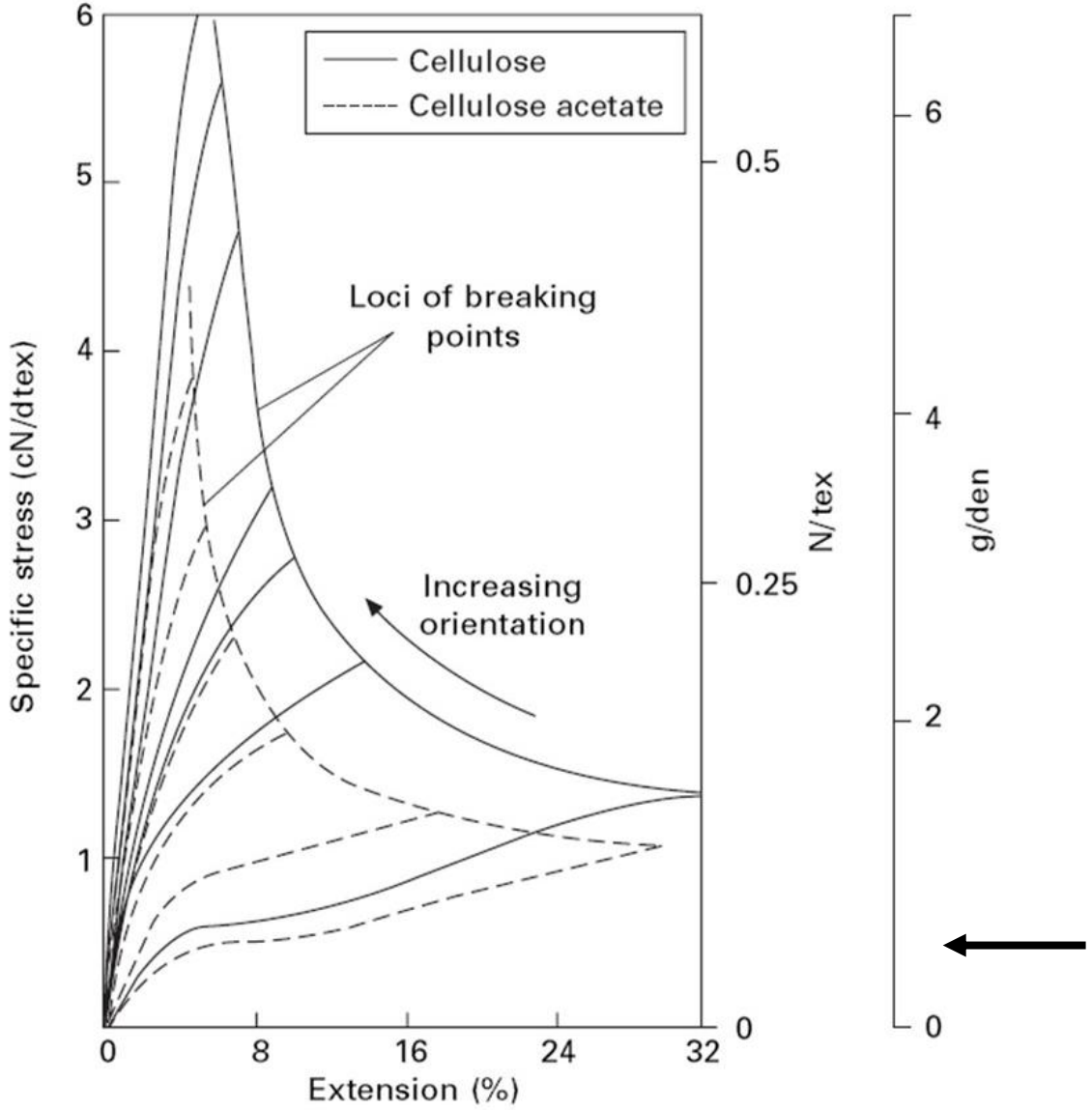
Crimp

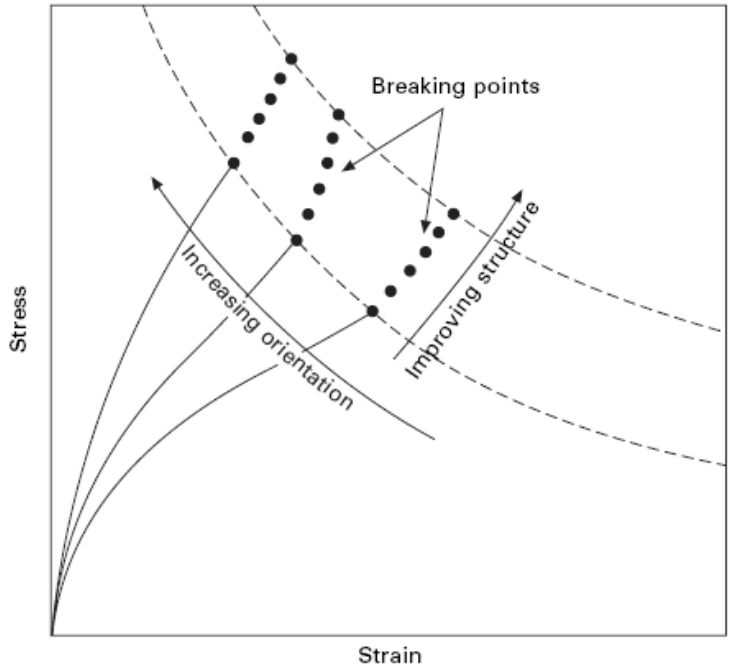




Mechanical classification of the fibre types: A, HM–HT fibre; B, weak inorganic fibre, e.g. rock wool; C, tough synthetic fibre; D, weaker textile fibre; E, elastomeric fibre.

Effect of Orientation



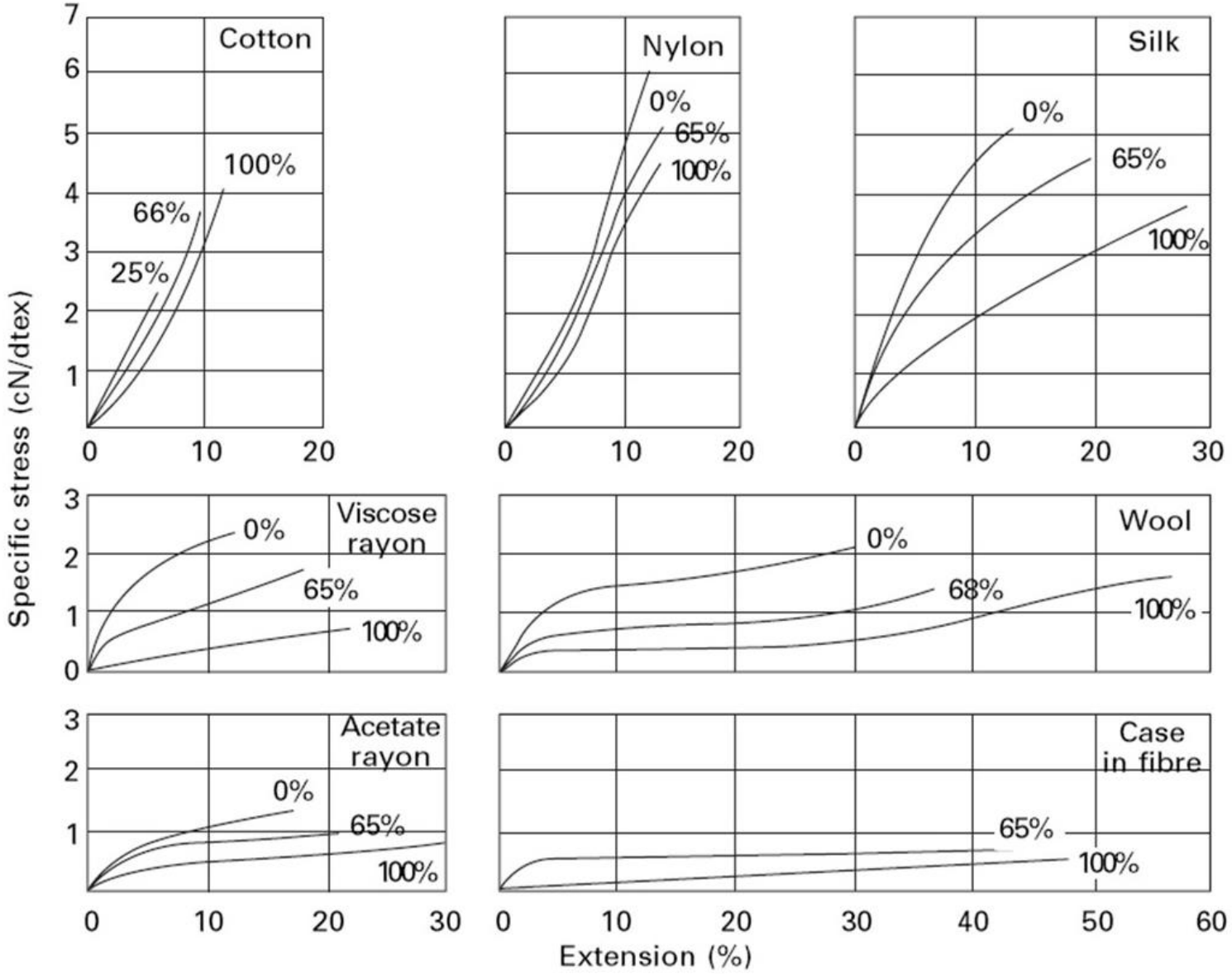


13.20 Load–extension curves for viscose rayon, showing changes produced by increasing orientation and improving structure.

Stress–strain curves of filaments of varying degrees of orientation. The dotted curves are secondary cellulose acetate and the full curves are cellulose fibres regenerated from acetate. The lowest curve in each set is for unoriented material.

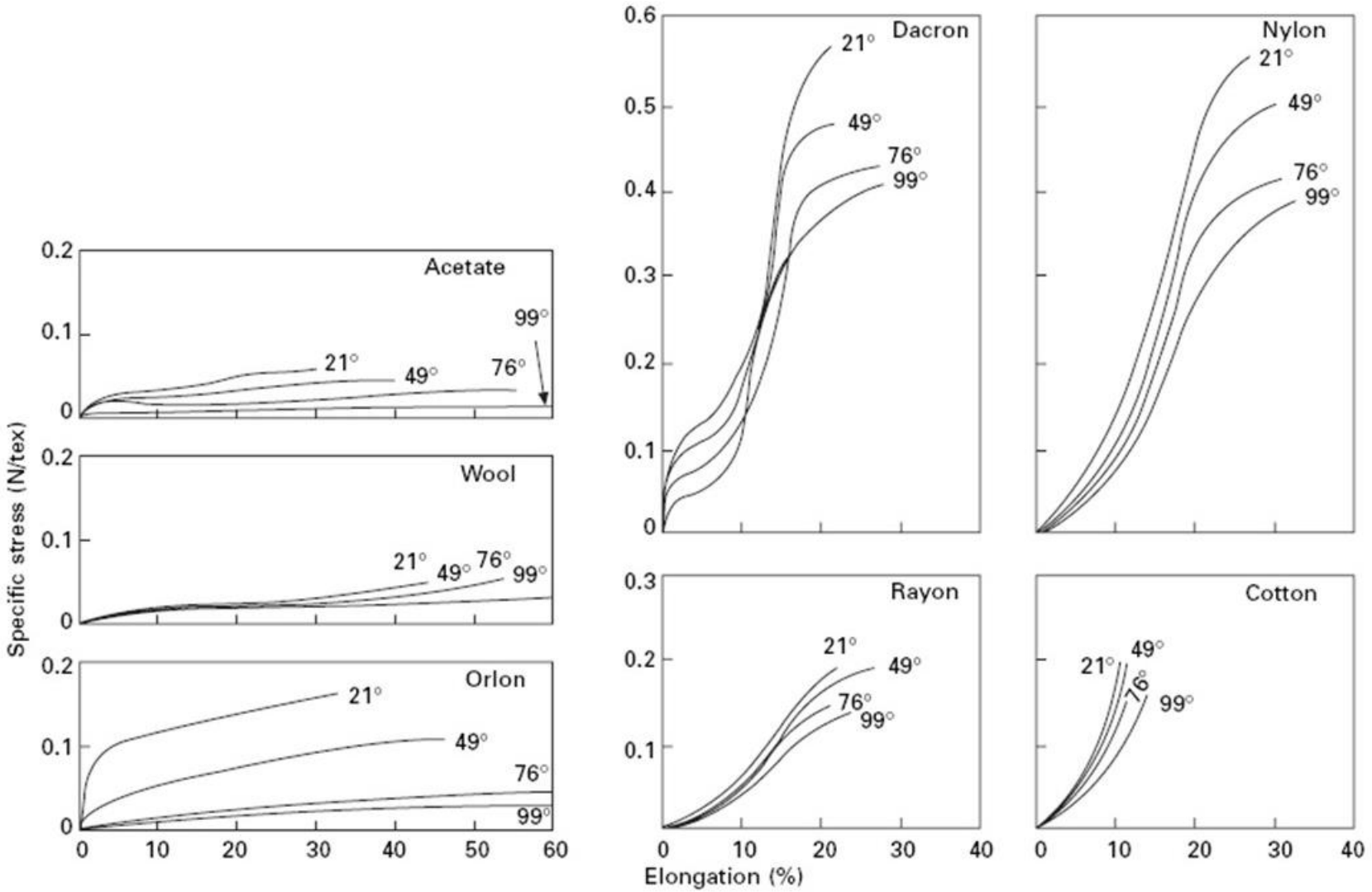
Effect of Moisture

Stress-strain plots at various humidity levels



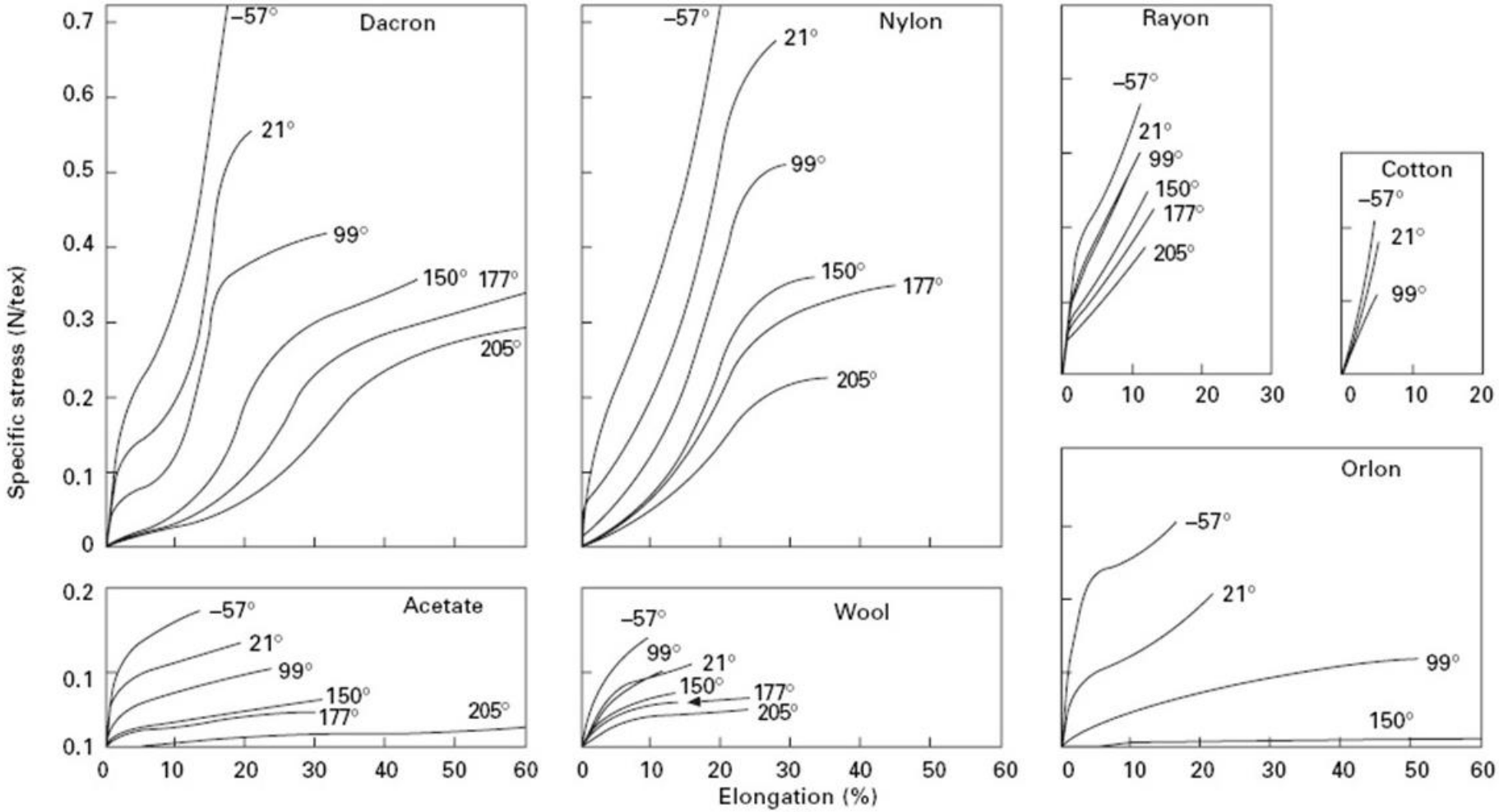
Effect of Temperature

Stress-strain plots at various temperatures (wet fibers)



Effect of Temperature

Stress-strain plots at various temperatures (dry fibers)



Property	Change with Increasing Degree of Crystallinity
Strength	Generally increases with degree of crystallinity
Stiffness	Generally increases with degree of crystallinity
Toughness	Generally decreases with degree of crystallinity
Optical Clarity	Generally decreases with increasing degree of crystallinity.Semi-crystalline polymers usually appear opaque because of the difference in refractive index of the amorphous and crystalline domains, which leads to scattering. Will depend upon crystallite size.
Barrier Properties	Small molecules usually cannot penetrate or diffuse through the crystalline domains, hence "barrier properties", which make a polymer useful for things like food wrap, increase with degree of crystallinity
Solubility	Similarly, solvent molecules cannot penetrate the crystalline domains, which must be melted before the polymer will dissolve. Solvent resistance increases with degree of crystallinity