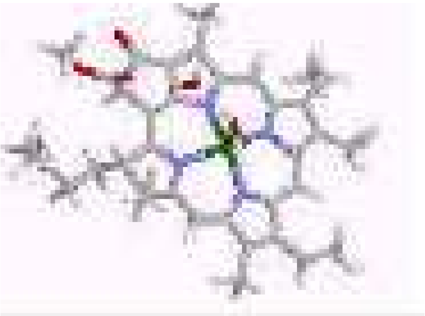
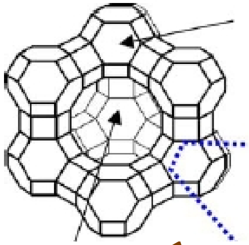
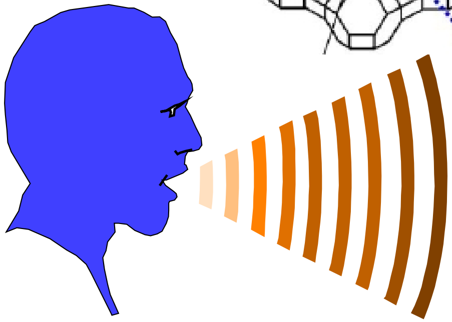




Materials for Intelligent Textiles





Jiří Militký

Department of Textile Materials,

Textile Faculty,

Technical University of Liberec

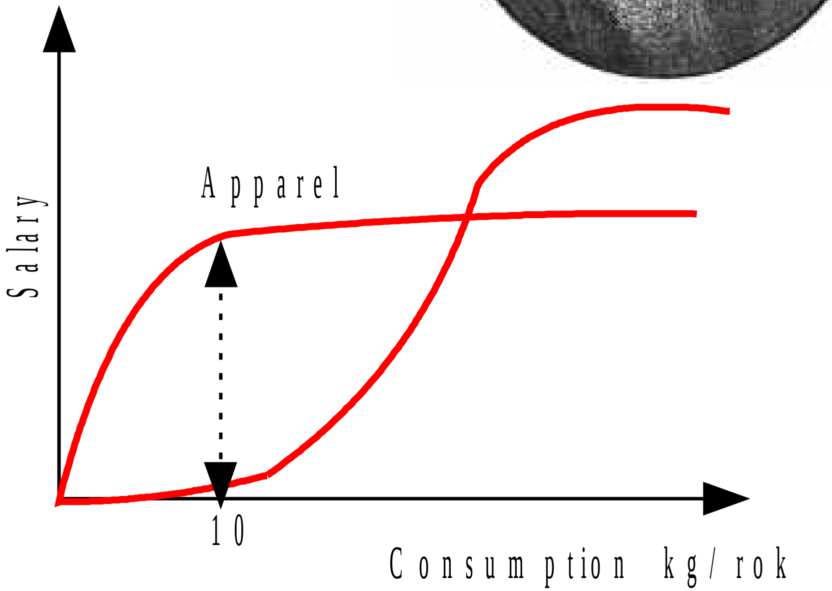
Textiles and manki

Textile products are accompanying humans during their whole life

Apparel – number of humans

(5-10 kg per year)

Technical – dependent on the state of knowledge



HighTech. vs HighTex.

High Tech
Raw materials
Production
Control
Finishing
Adds on
(Productivity,
energy
ecology
prope

High Tex
Properties
Performance
Design
Functions

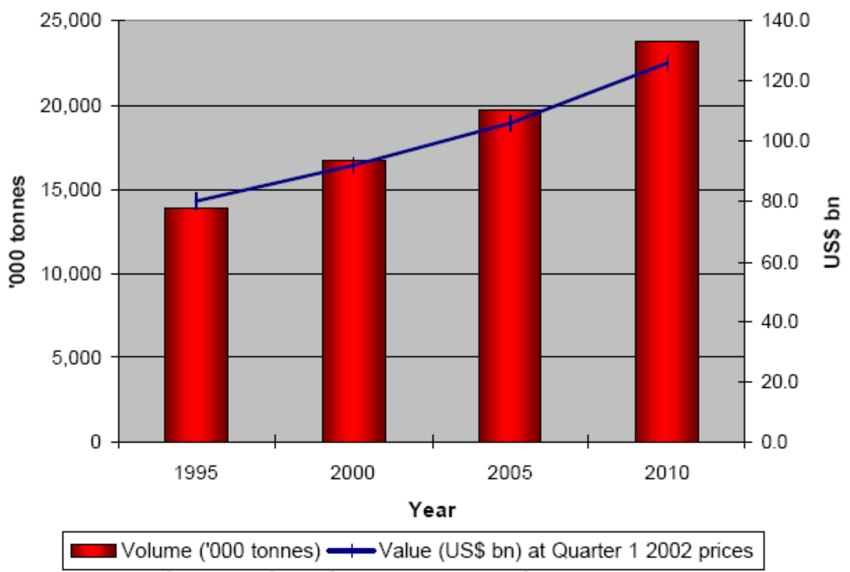
(New functions,
improved properties
deterioration of

Apparel Textiles

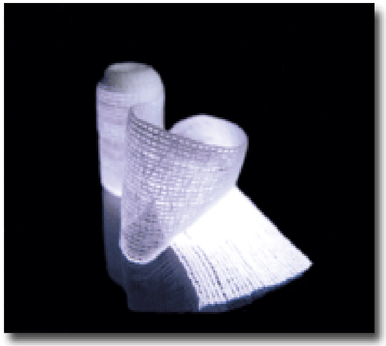
- Fashion
- Comfort
- Protection
- Information
- Sport

Technical textiles

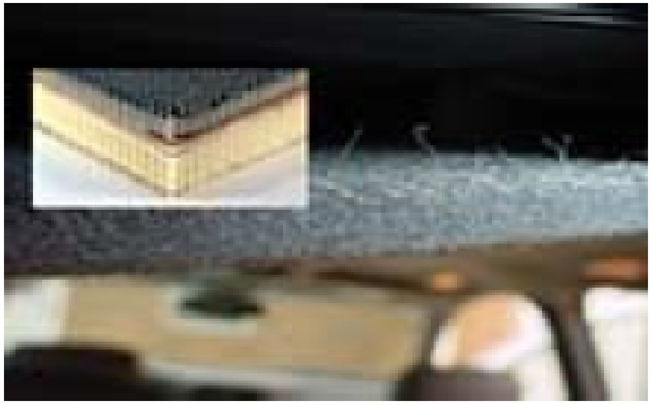
- Medical textiles
- Geo textiles
- Textiles for transport
- Composites
- Protective textiles
- Textile electronics
- Etc.



World technical textiles consumption



Automotive textiles



The automotive industry is the largest user of technical textiles, which about 20 kg in each car of the 45 million or so cars made every year world wide.

3.5 kg seat covers

4.5 kg carpets

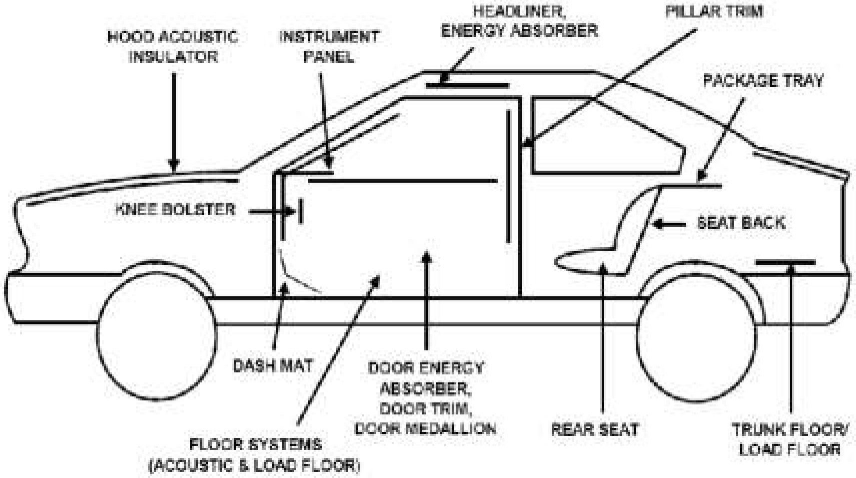
6 kg other interior textiles

6 kg composite (glass fibre)

10 m^2 upholstery fabrics

8.5 m^2 trim items (including floor covering)

Foam textile interfaces



Main aim

Integration of the results of the recent development of material engineering, technology and chemistry or physics for the purposes of the creation of new textile structures with special properties suitable for the production

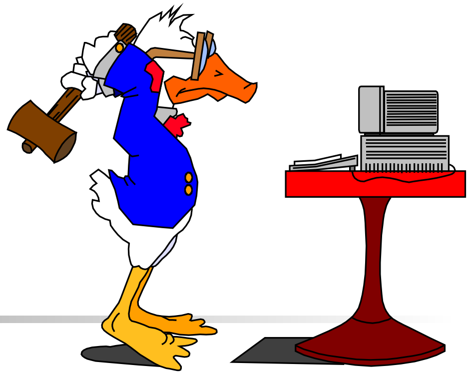
- **“intelligent” apparel textiles**
- **technical textiles with specified properties.**

Smart structures

- Synthesize new materials and structures at the atomic or molecular level with smart functionality
  - New discoveries are required
  - Technologies are immature

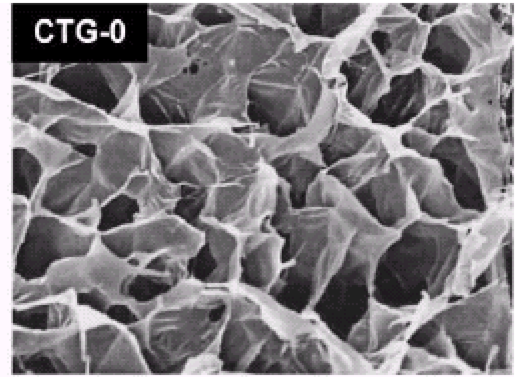
- Synthesize new materials and structures by compositing known constituents
  - Active elements attached to the structure (parasitic)
  - Active elements embedded in the structure

Intelligence



- Artificial intelligence – intelligent = able to create decision on the base of external stimuli (sensorial, mechanical, chemical etc.).
- Intelligent structures – intelligence = ability of positive reaction to exte stimuli.

Stimulus / Respons



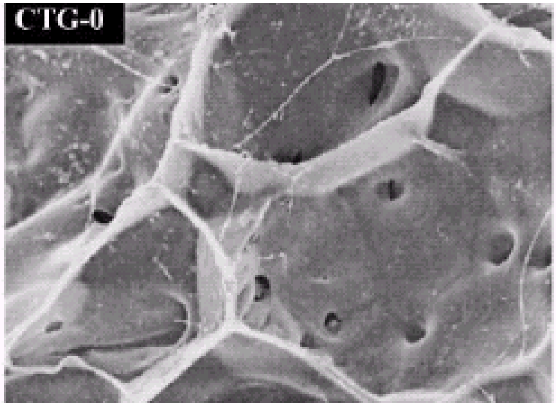
Stimulus (change) S

Electromagnetic energy (UV, visible, IR radiation)

Chemical energy (moisture, presence of ions, etc.)

Mechanical energy (pressure, break, twist, atd.)

Response (change..) R



Shape (swelling, shrinking)

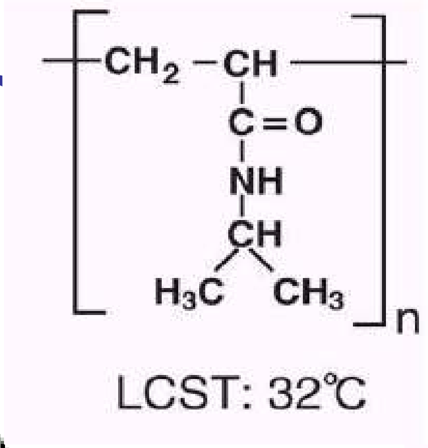
Colour (shade, intensity)

Electrical conductivity

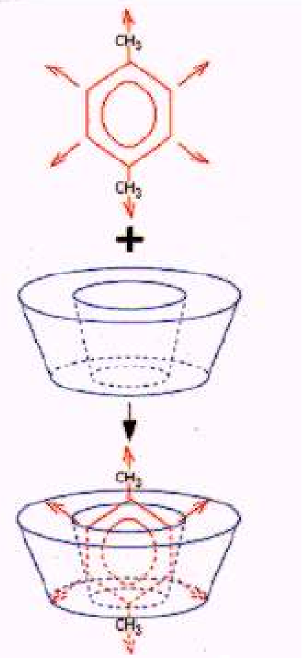
State of matter (phase change, crystallinity etc.)

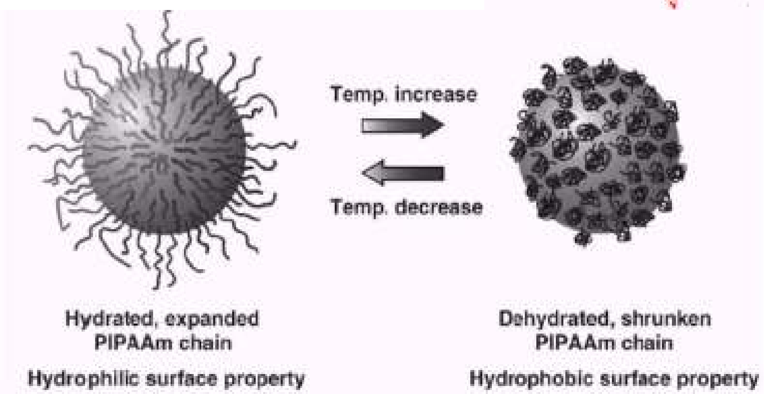
Materials for smart structur

- Electroactive Ceramics
    - Piezoelectric (PZT)
    - Electrostrictor (PMN)
    - FE-AFE Phase Change (PLZT)
    - Single Crystal Piezoelectric (PZN)
- Alloys
    - Shape Memory (Nitinol)
    - Magnetostrictive (Terfenol)
    - Magneto Shape Memory
- Glass Fiber Optic
    - Bragg Grating
    - Long Period Grating
- Polymers
    - Electroactive (PVDF,polyelectrolytic gels, semiconducting)
    - Electro- and Magnetorheological Elastomers



LCST: 32℃





Nano materials are not included here

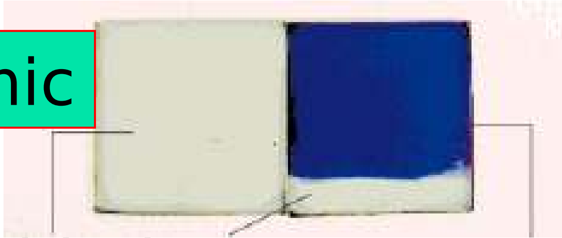
Innovative textil

- “Intelligent” body adaptive response apparel textiles having improved comfort controlled by the state of microclimate and wearers needs.
- “Intelligent”-knowledge based technical textiles with specified properties (e.g. locally compressive behaviour) and complex actions (comfort type mattresses for disabled persons, intelligent car seats etc.)
- Hybrid multifunctional textiles for protective clothing combining improved protection (a barrier against the selected types of radiation and particles) with improved comfort.

Intelligent textiles

- Sensitive to external fields (ph, radiation, electric, magnetic, mechanical fields). PASIVE
- Changing properties (usually form) as response to external field changes ACTIVE

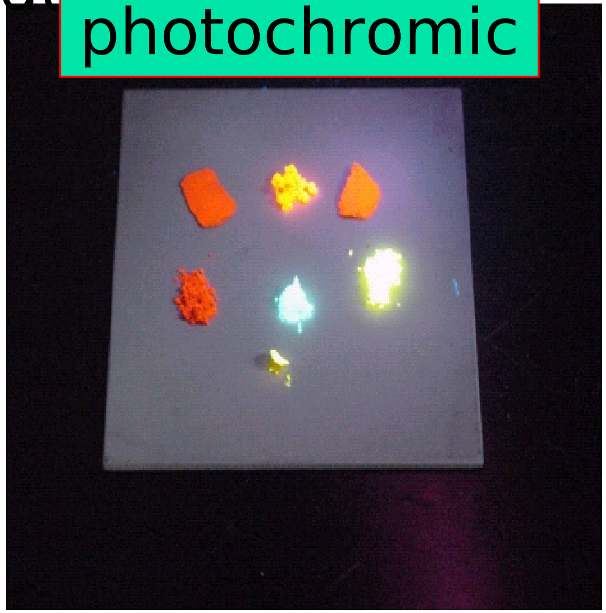
electrochromic



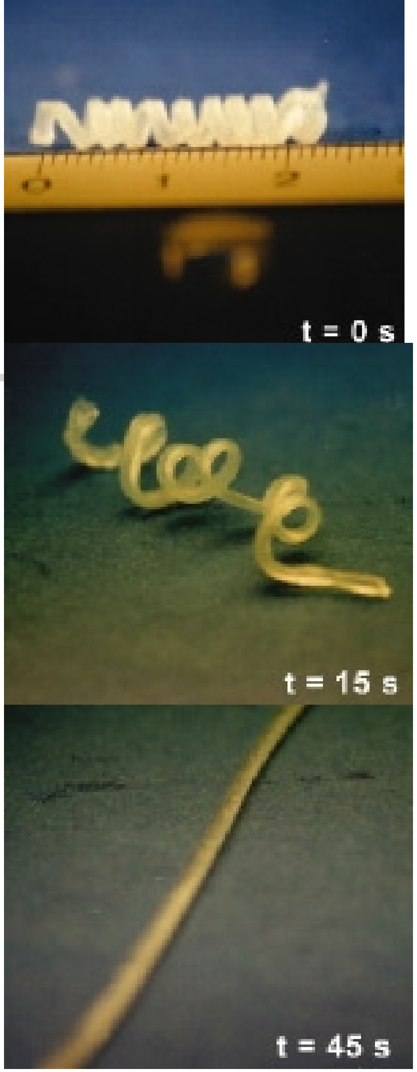
oxidation
reduction

diabetes

photochromic



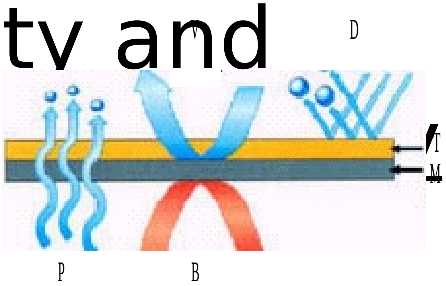
Active intelligent textiles

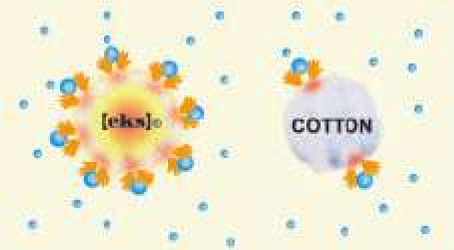


- <u>Shape memory</u>

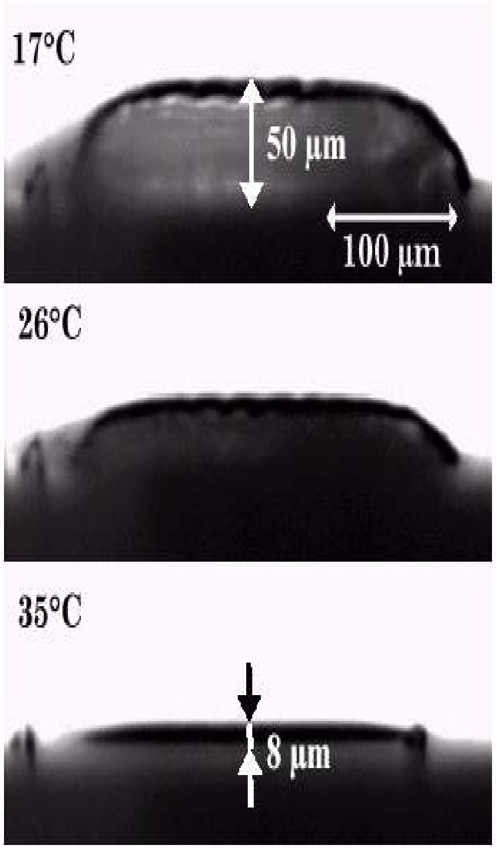
(reversible form changes due to heating and cooling)

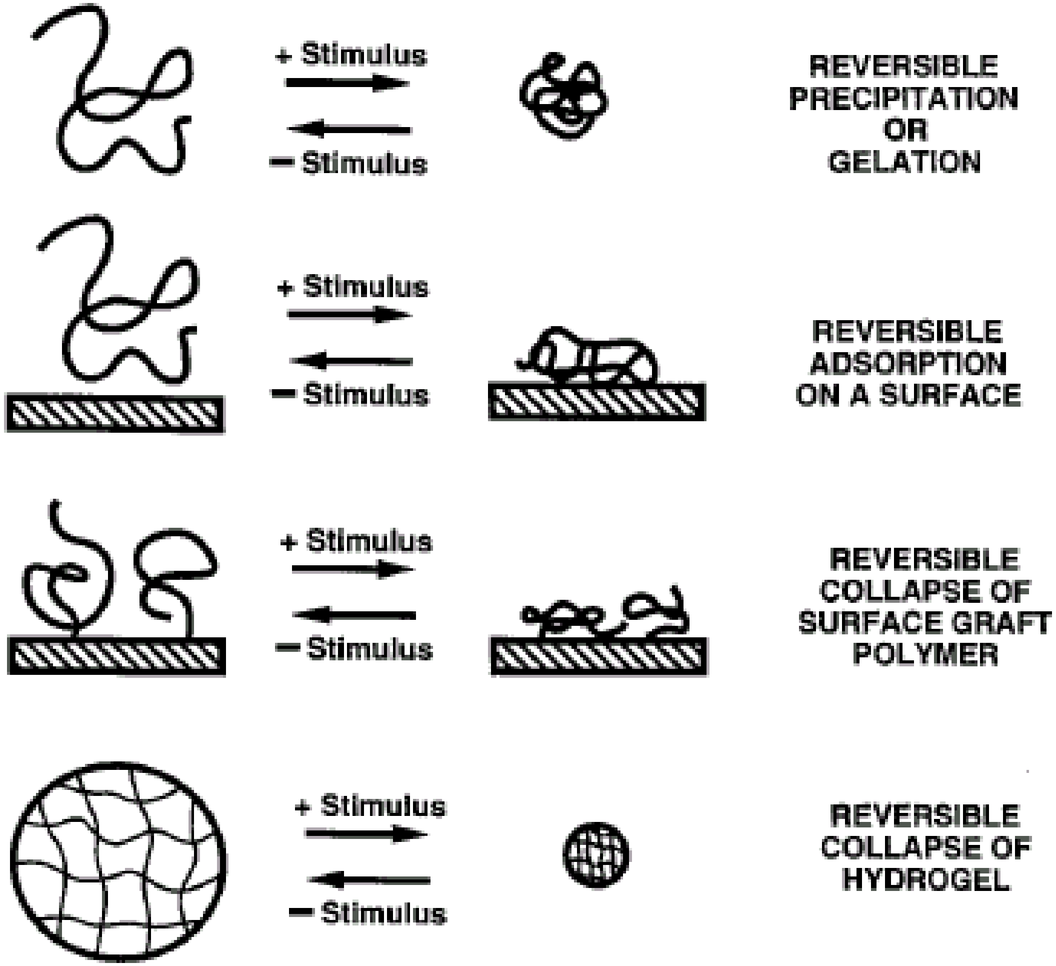
- <u>Heat storing and evolving materials</u>
- <u>Variable porosity and water vapor pe</u>





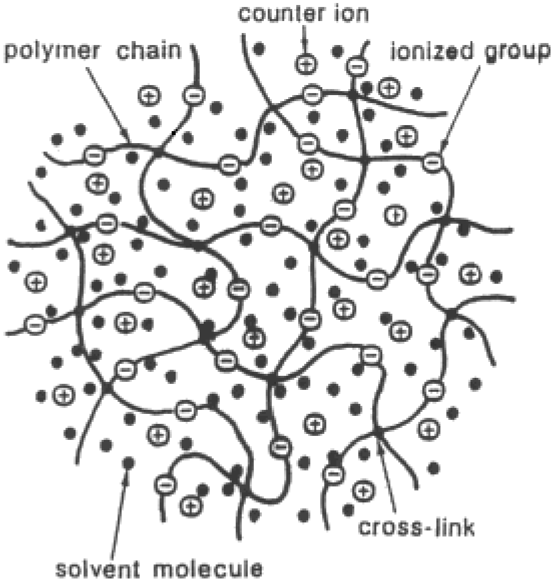
Stimuli Sensitive Materials

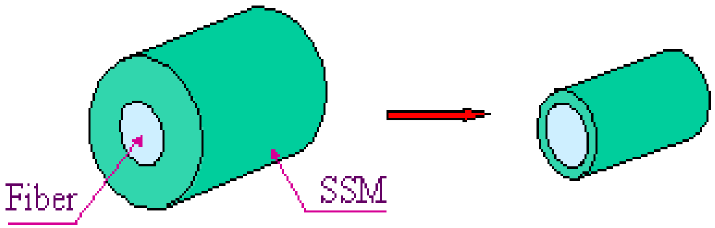


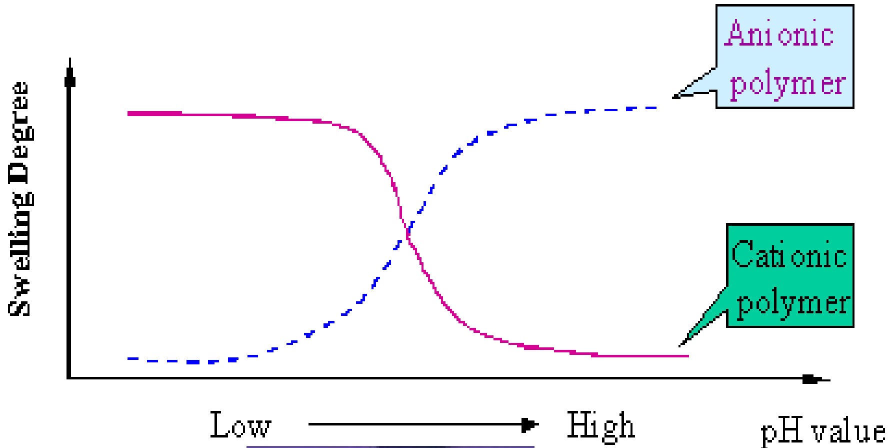


pH sensitive materials

- Polyeletrolytic gels

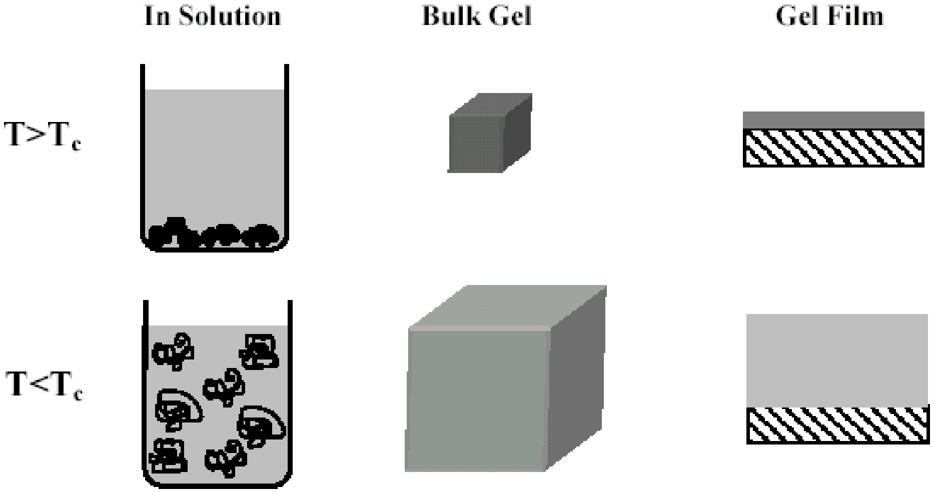






Thermo sensitive materials

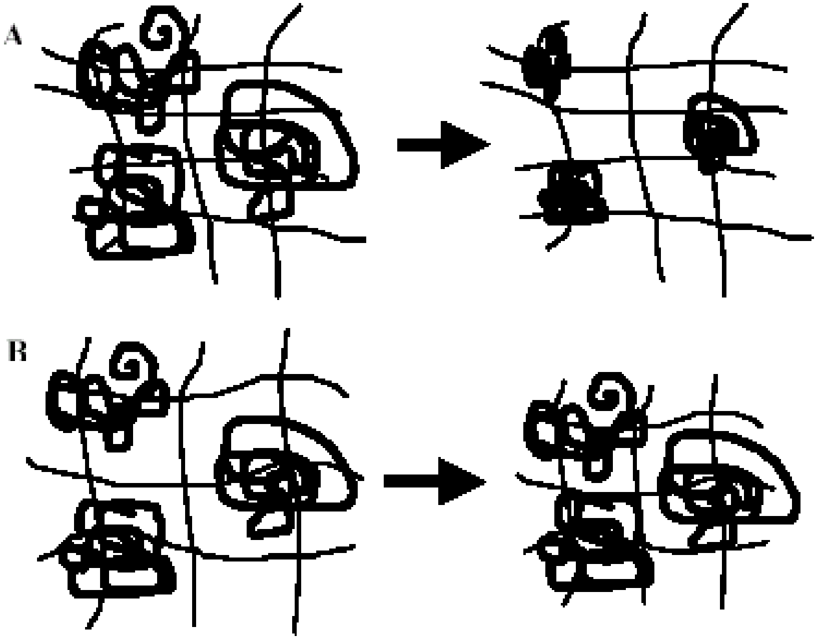
- Lower
- Critical
- Solution



Ether groups
  Poly(ethylene oxide)
  Poly(EO/PO)[a] random copolymers
  PEO-PPO-PEO triblock surfactants
  Alkyl-PEO block surfactants
  Poly(vinyl methyl ether)
Alcohol groups
  Hydroxypropyl acrylate
  Hydroxypropyl methylcellulose
  Hydroxypropyl cellulose
  Methylcellulose
  Poly(vinyl alcohol) derivatives
Substituted amide groups
  Poly(N-substituted acrylamides)
  Poly(*N*-acryloyl pyrrolidine)
  Poly(*N*-acryloyl piperidine)
  Poly(acryl-L-amino acid amides)
Other
  Poly(methacrylic acid)

IPN with termosensitive materials

- A – coils are swollen hydrophilic or collapsed hydrophobic
- B – coils are swollen hydrophilic independently on temperature



T low T high

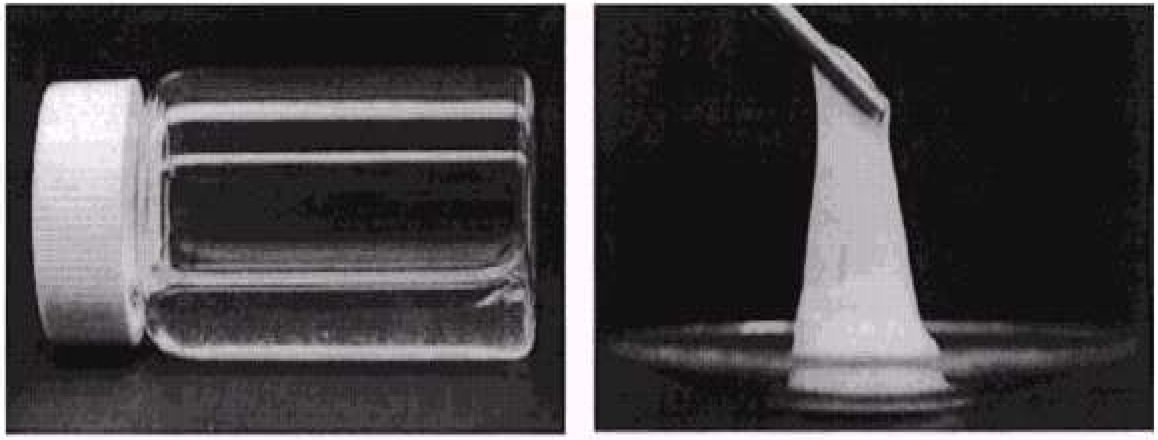
Trends in Biotechnology 20, 305 (2002)

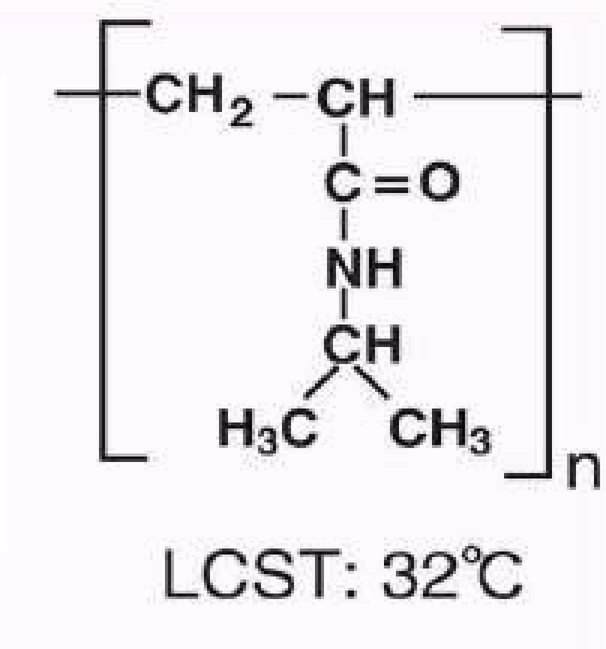
PNIPAAm

Poly N-izopropylakrylamid and copolymers

Soluble in water below 32^{o}C precipitation above 32^{o}C.

Transition helix coil



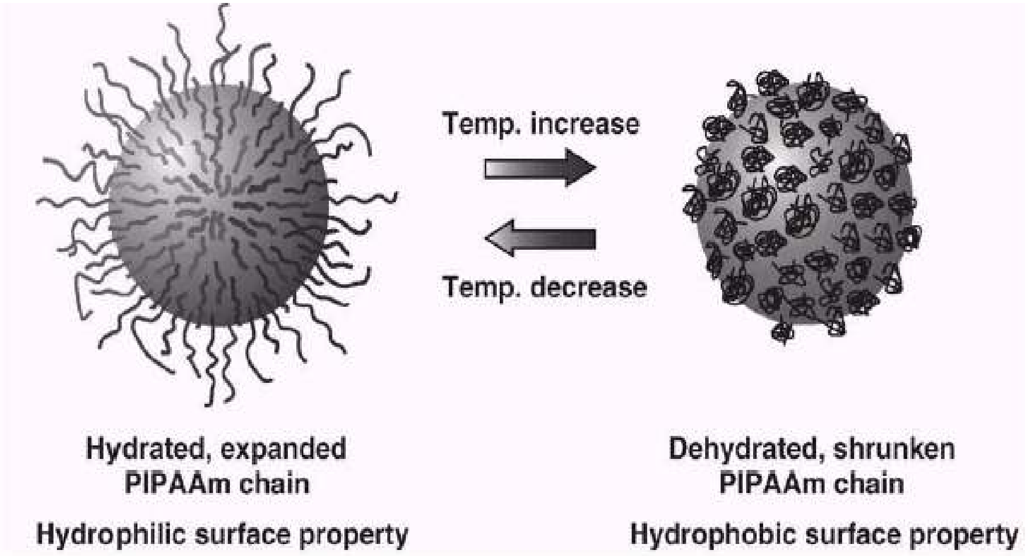


PNIPAAm properties

- Stimuli: temperature, ionic strength, pH, light, electric and magnetic field
- Response: shape, surface, sol-gel transition, solubility

Sol-gel: near IR, magnetic field, colour change- red shift (lower wavelength)

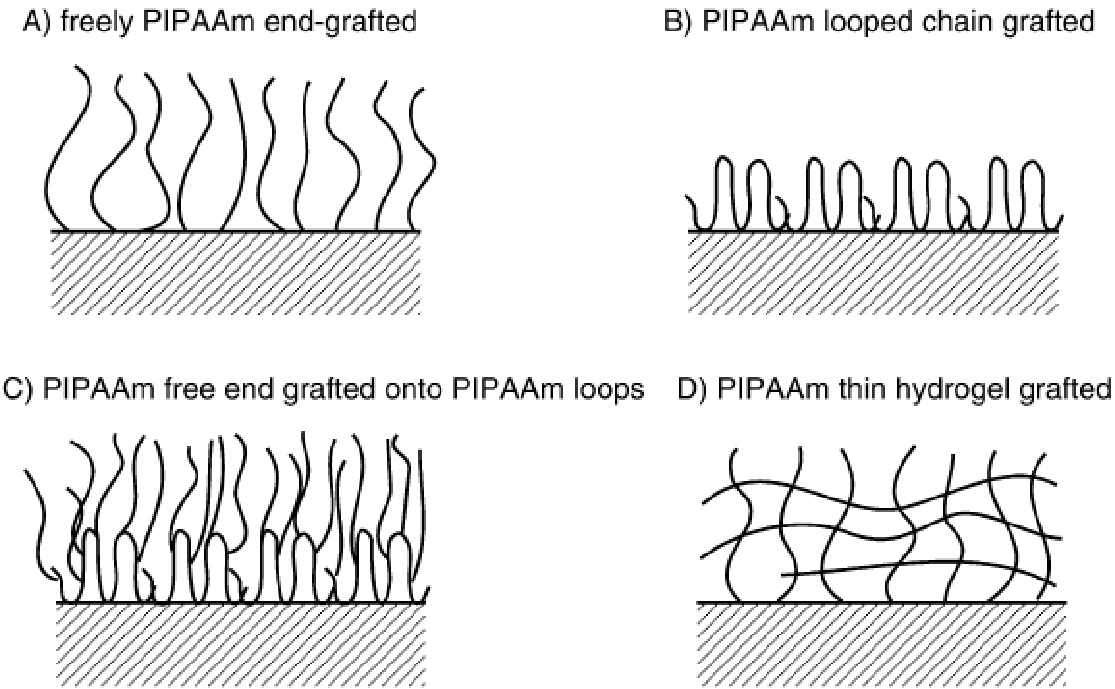
<u>Application:</u> bio-medicine, control dosing, sensors



Poly N-izopropylakrylamid on cotton

below 32°C hydrophilic above 32°C hydrophobic

PNIPAAm response

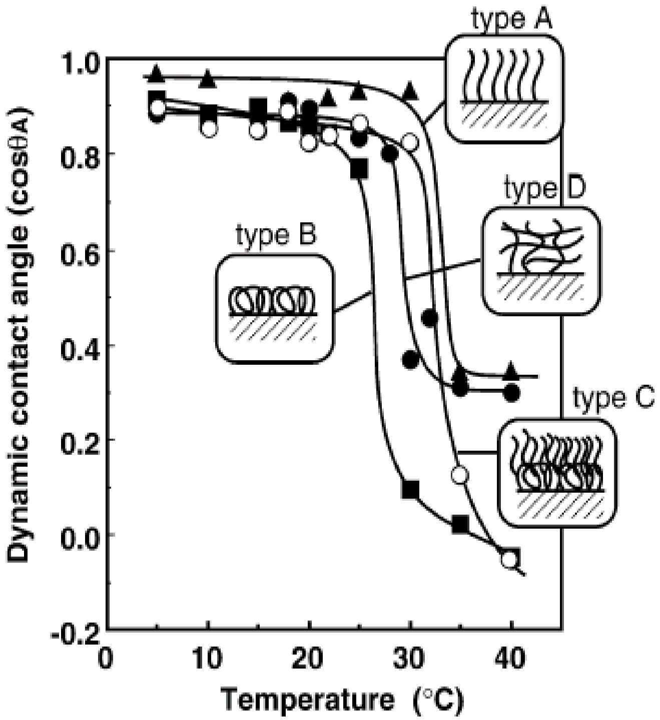


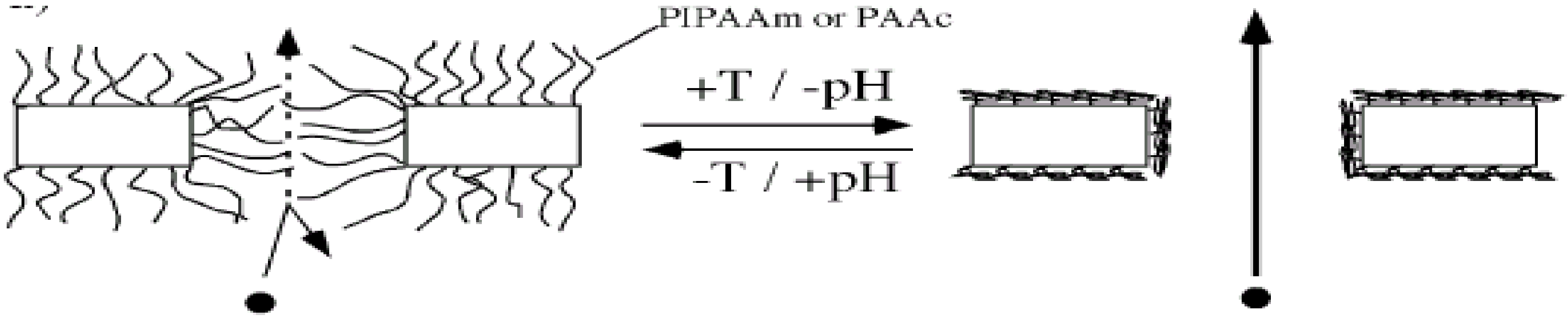
A) freely PIPAAm end-grafted

B) PIPAAm looped chain grafted

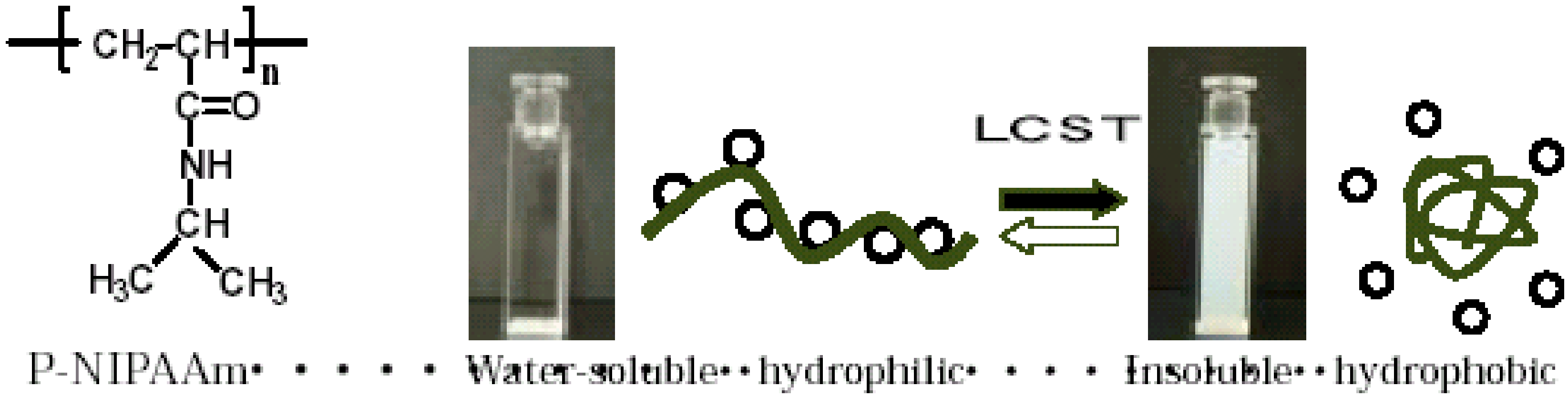
C) PIPAAm free end grafted onto PIPAAm loops

D) PIPAAm thin hydrogel grafted

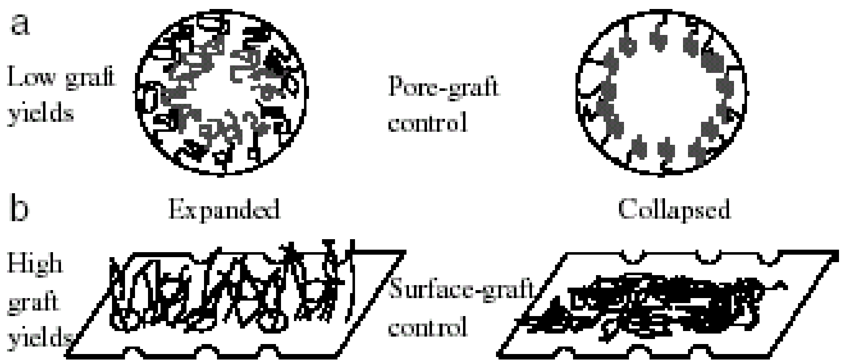




Porosity control

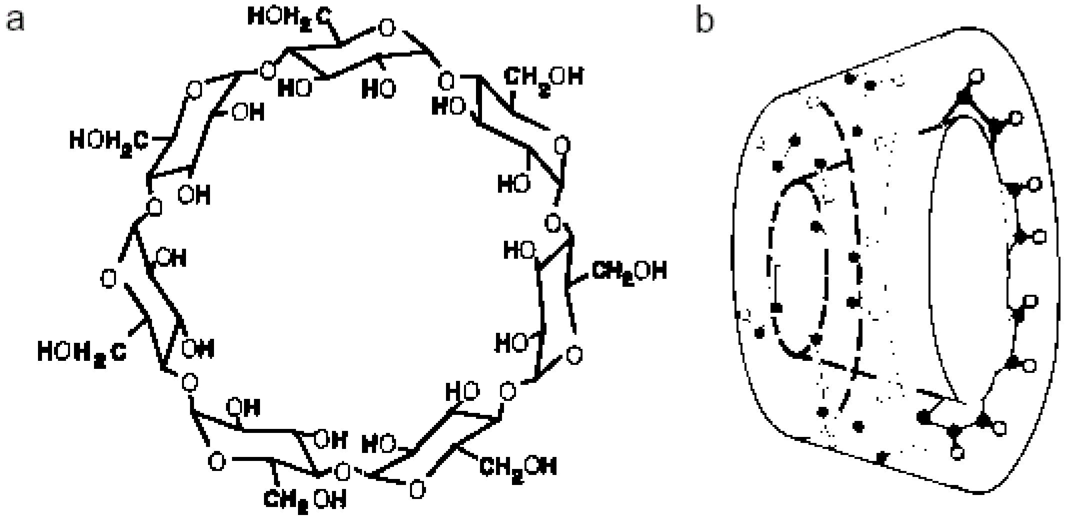


- Porosity control via amount of grafted material



Cyclodextrines - basic

- Polysacharides bu from six to eight D glucose units
- Torus shaped with hydrophobic cavities
- Formation during enzymatic degradation of starch



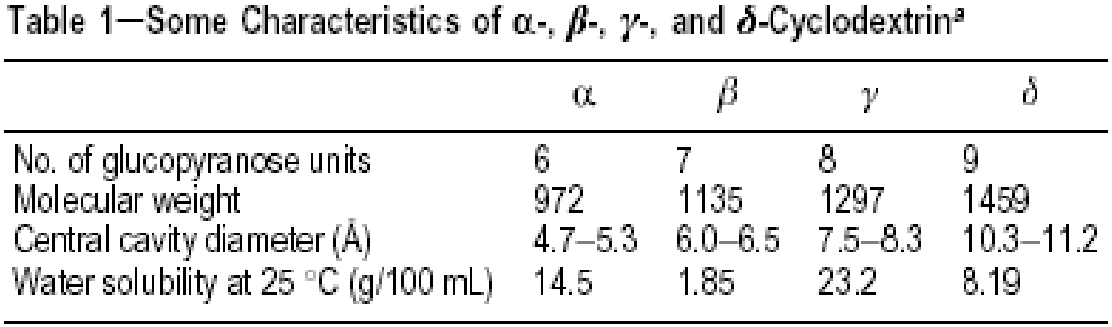
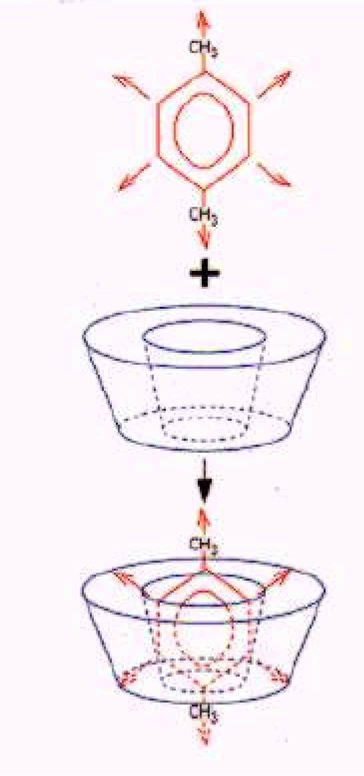
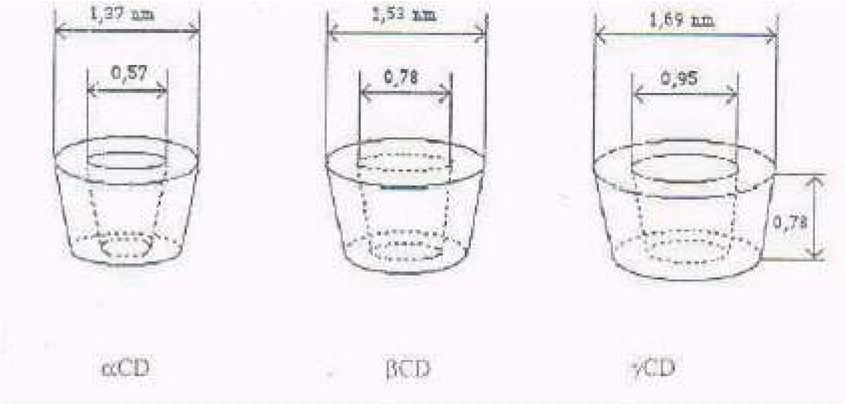


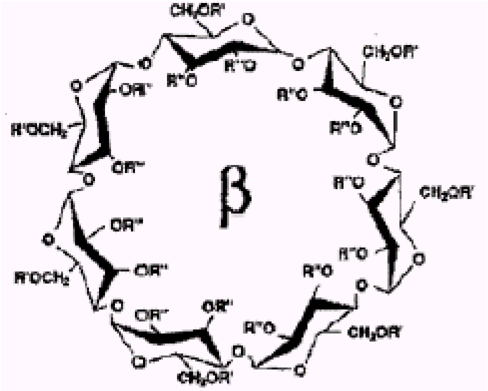
Table 1—Some Characteristics of α-, β-, γ-, and δ-Cyclodextrin[a]

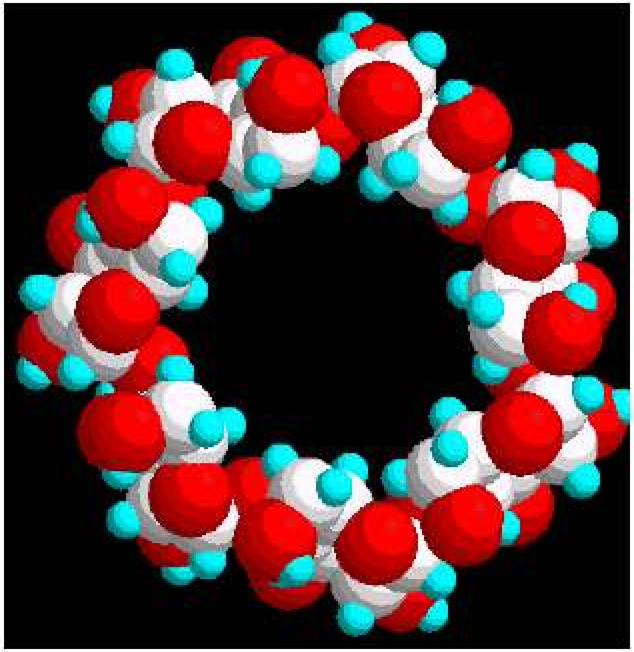
	α	β	γ	δ
No. of glucopyranose units	6	7	8	9
Molecular weight	972	1135	1297	1459
Central cavity diameter (Å)	4.7–5.3	6.0–6.5	7.5–8.3	10.3–11.2
Water solubility at 25 °C (g/100 mL)	14.5	1.85	23.2	8.19

Cyclodextrines trap





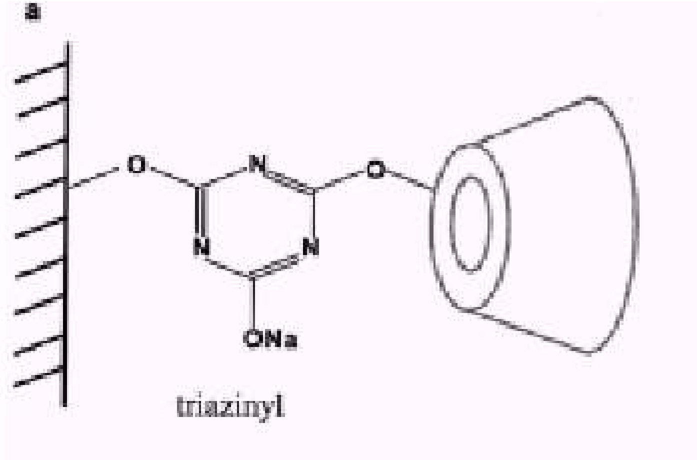




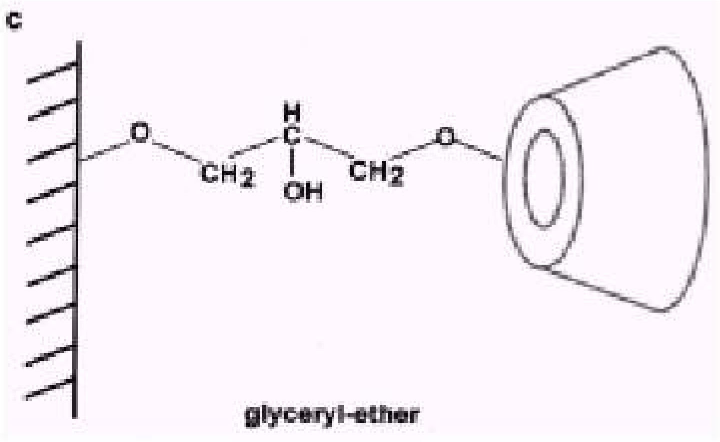
- Cyklodextrines
- Molecular traps

„Wacker Specialites“

Cyclodextrines anchoring



triazinyl



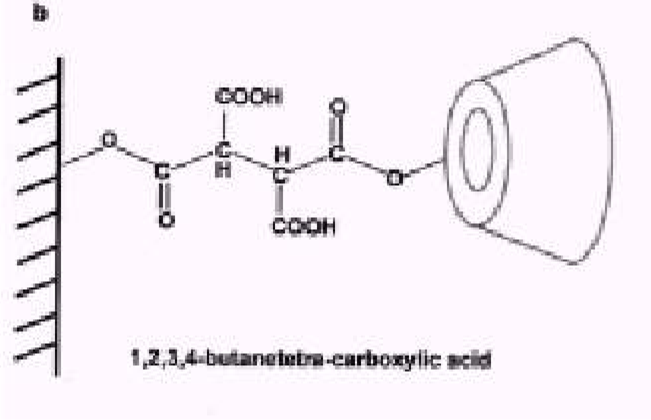
glyceryl-ether

Permanent fixation

Cellulose fibres – triazinyl groups

PES fibres – log alkyl chains

PA fibres – sulfonic acid groups



1,2,3,4-butanetetra-carboxylic acid

Cyclodextrines applications

Sweat removal, odor absorption

Perfumes

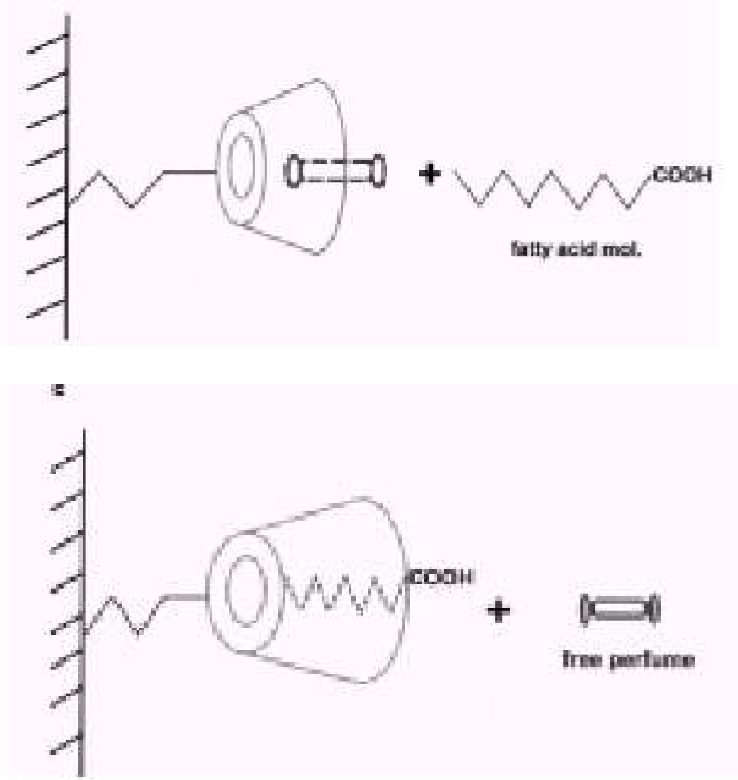
Detergents – defoaming

Dyeing surfactants

(fastness, solubility)

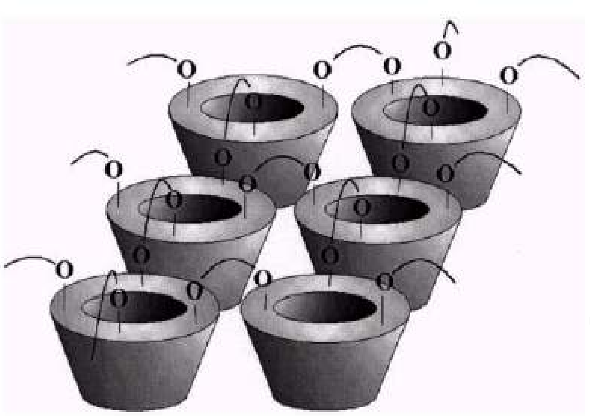
Antibacterial finishing

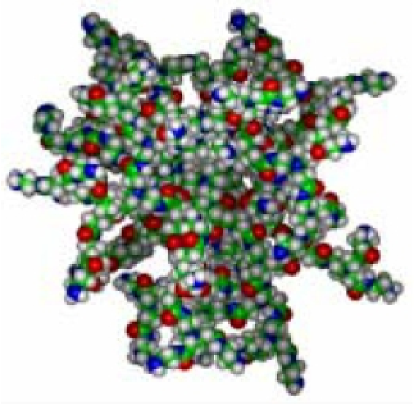
Effluents treatment

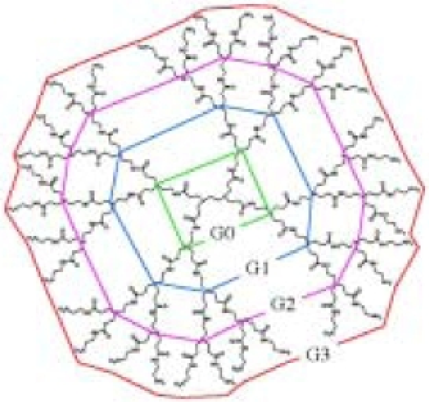


Specialty polymers

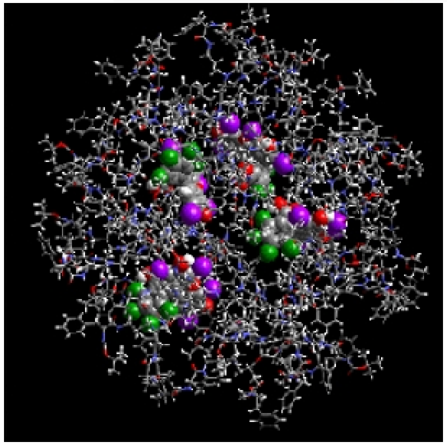
- The integration of macrocycles to polymers (bifunctional linkers epichlorhydrine)

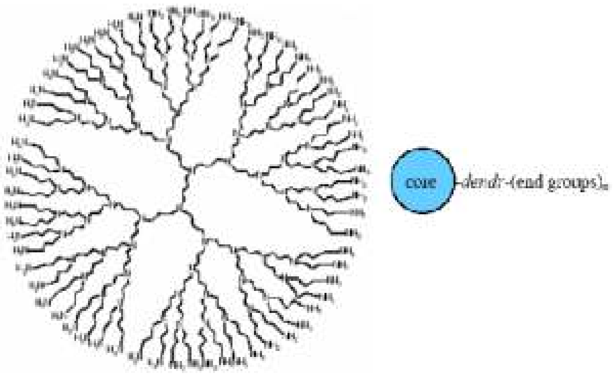




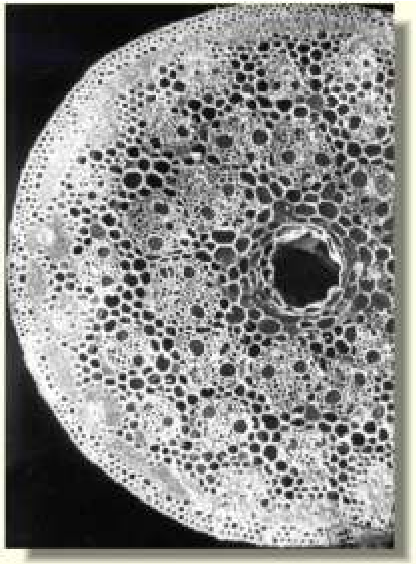


- **Dendrimers** highly branched with selective traps and cages



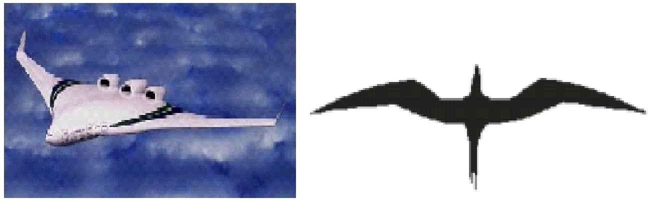


Biomimetics –development



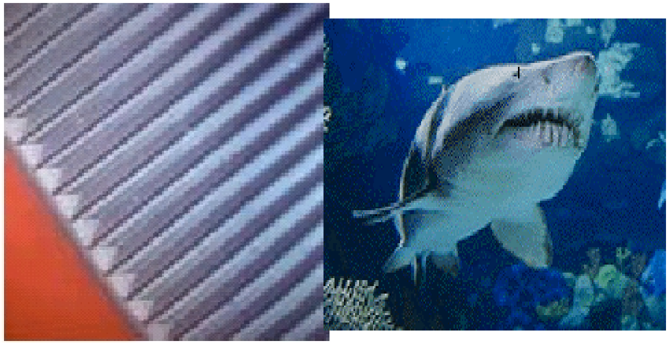
- **1960** Jack Steele - bionics as science dealing with systems copying some functions from nature.
- **1972** Breslow - *biomimetic chemistry* combination of bio

  and mimetic (imitation).
- **1987** Pederson a Cram - Nobel prize in chemistry (synthesis of ether rings for creation of artificial enzymes and cell membranes)



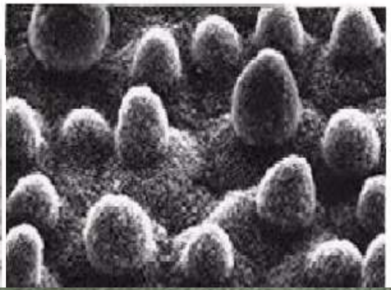
Obr.1

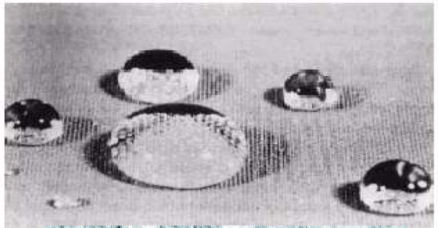
Biomimetics

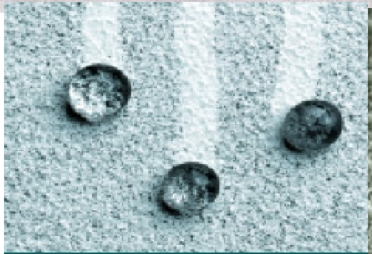


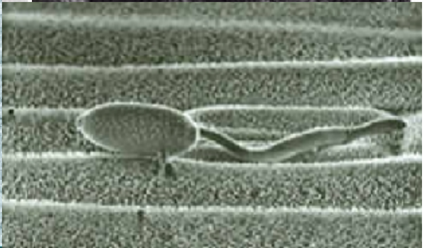
Obr.5

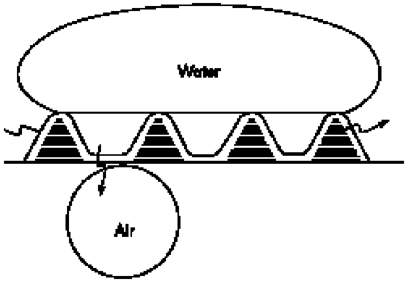
- **Kelvin** mirror galvanometer - analogy with sun rays reflected from his monocle
- **Georges de Mestral** Velcro zipper – analogy with special seed entagled to hid dog hackles.
- **Leonardo da Vinci** flying machines – analogy with bird flight

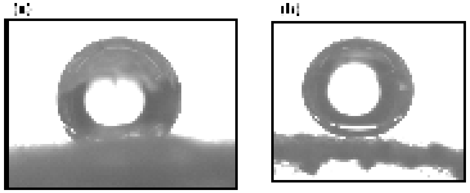


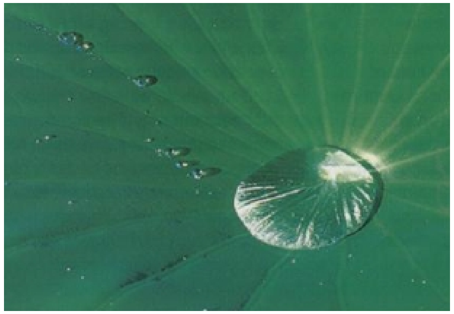






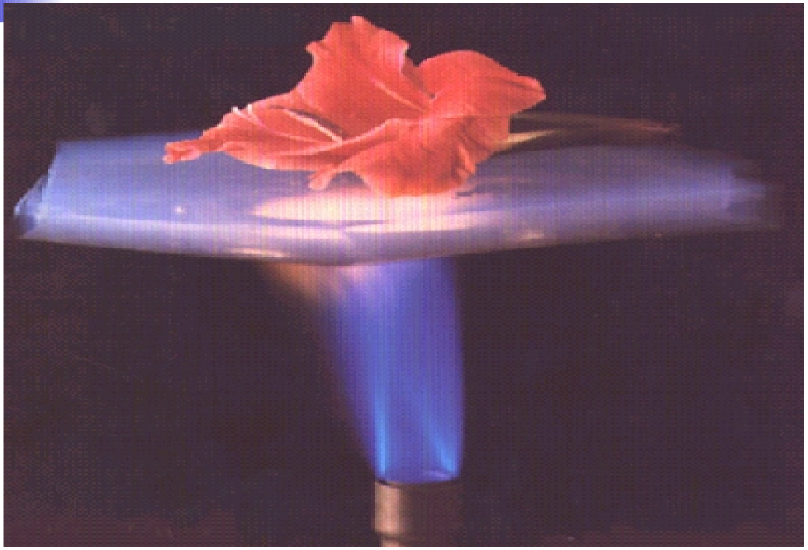




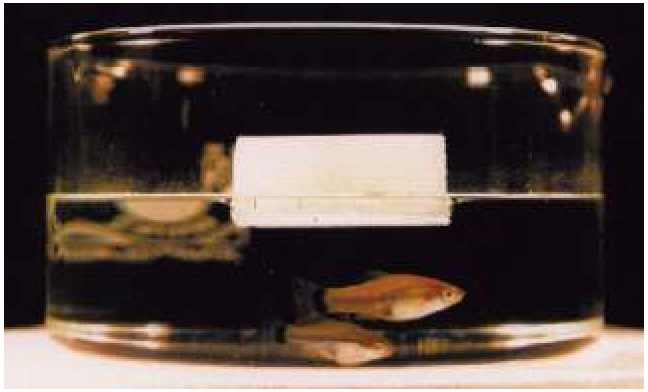


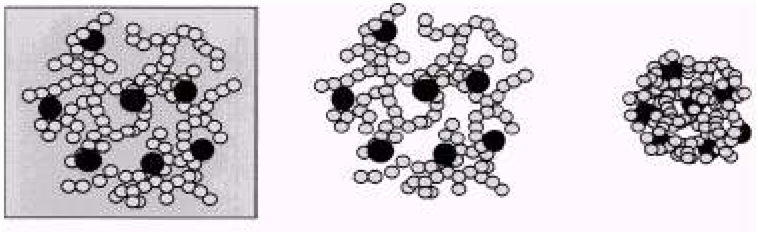
LOTUS effect

Specialty Materials



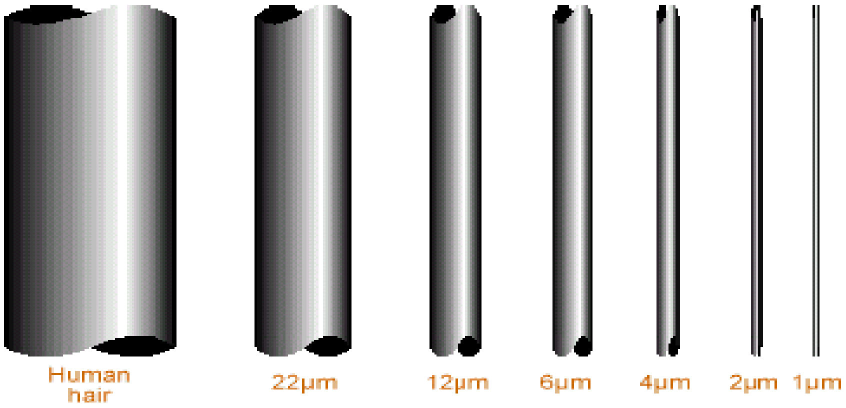
- Aerogels
- Piezoelectric layers and fibers
- Nano composites
- Chameleonic fibers

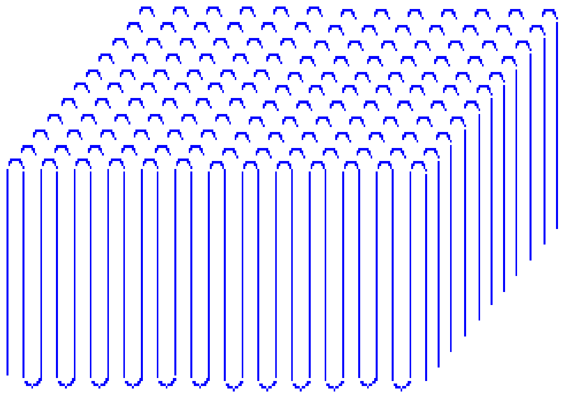




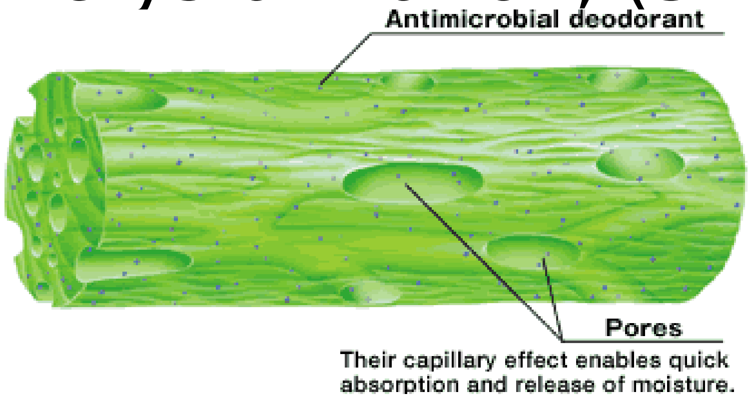
Textile fiber

- **Fibrous structure** due to orientation of macromolecules along fiber axis and partial crystallization, (3D





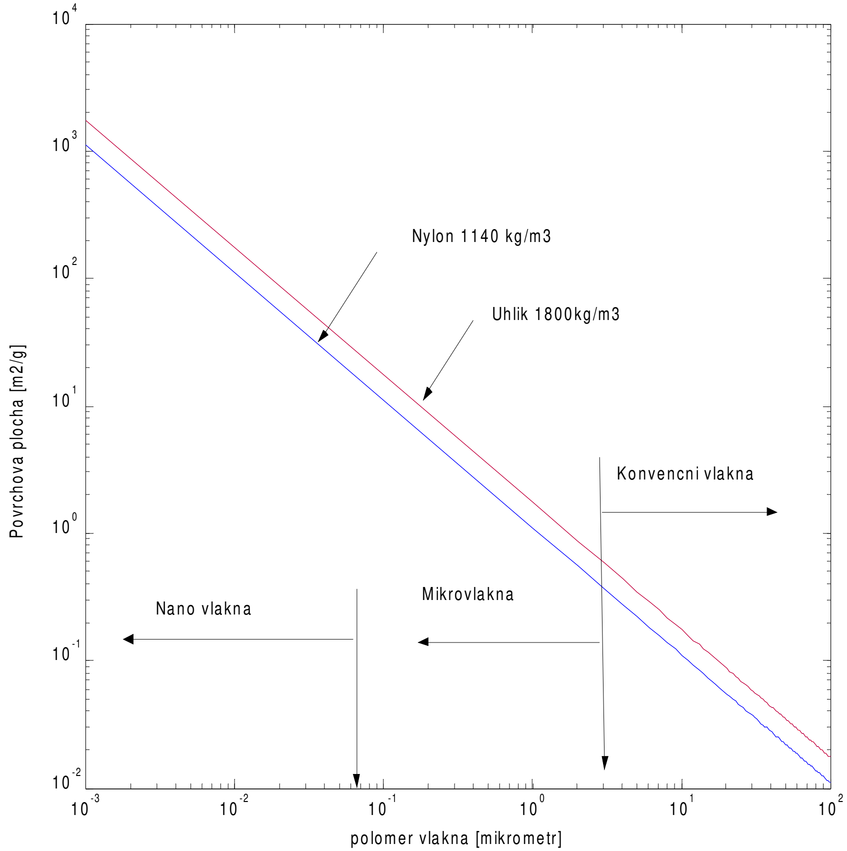
They can fold, and they can stack. A stack of polymer chains folded back on themselves like this is called a *lamella*.



Extremely high relative surface area

Relative surface area **S_p** [m² g⁻¹] is surface area of fiber divided by corresponding mass. For circular fibers (radius *r) is*

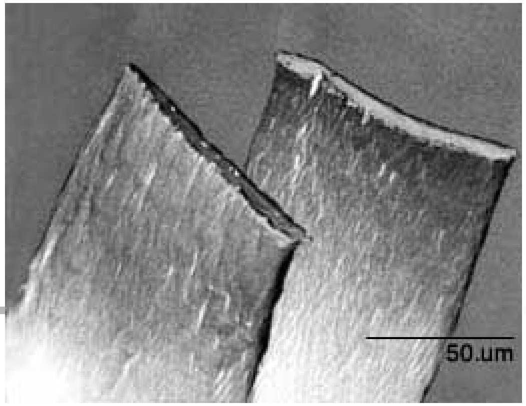
$$S_p = \frac{2\pi * r * l}{\pi * r^2 * l * \rho} = \frac{2}{r * \rho} = \sqrt{\frac{4 * \pi}{T * \rho}}$$

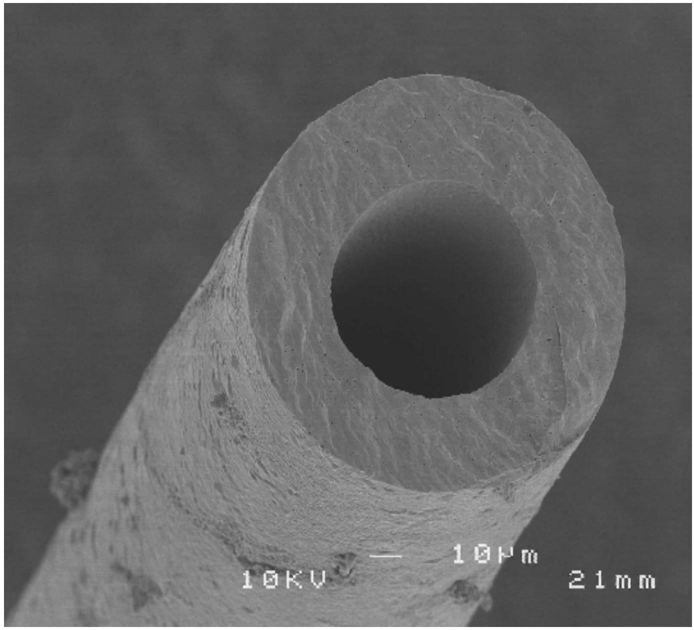


Shape variation

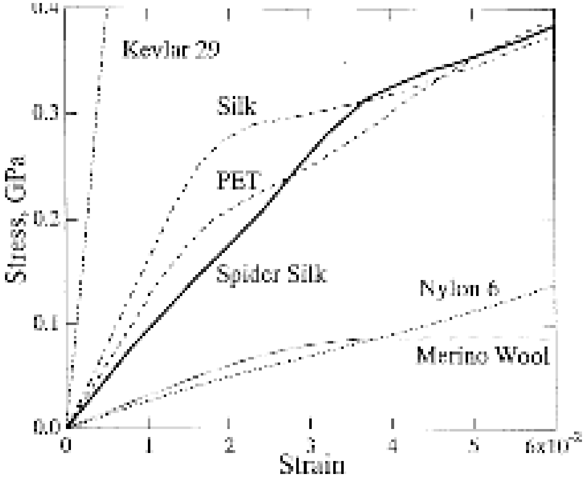
- Cross section shape
- Hollow fibers

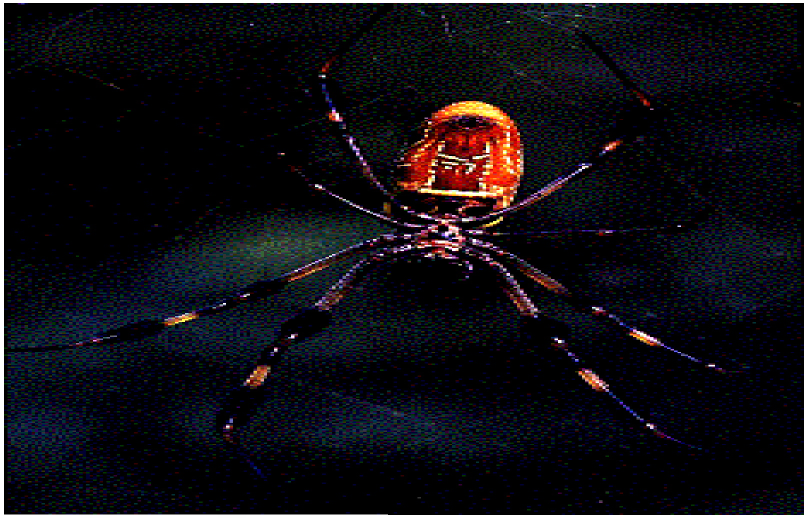
s

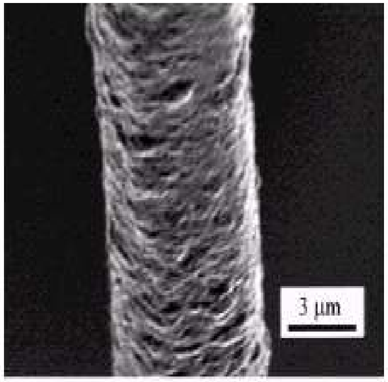


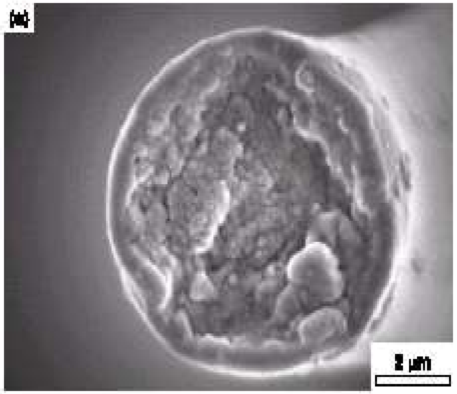


Spider silk







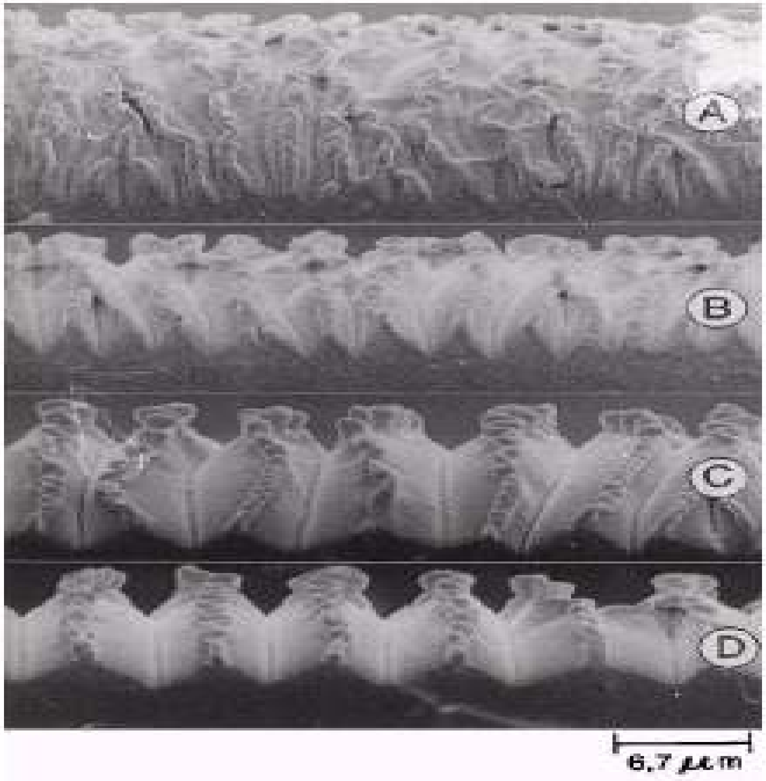


- Spinning from aqueous solution of polypeptides at room temperature.
- Solidification on the air.
- Fibers are resistant against weather and are durable.
- Fibers are biodegradable and reusable.

Tenacity = 1,75 GPa

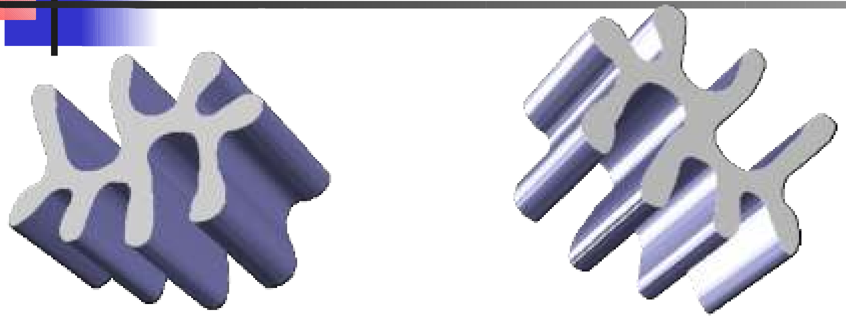
Compressive strength = 0,05 GPa

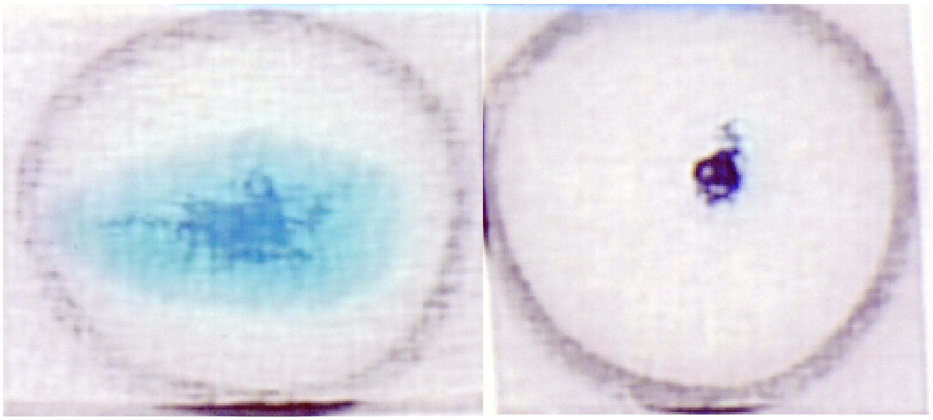
High functional fibers



- **New polymers**
- **Additives and dopes (conductive fibres)**
- **Surface geometry changes**
- **Controlled degradation**

Deep grooved fibers

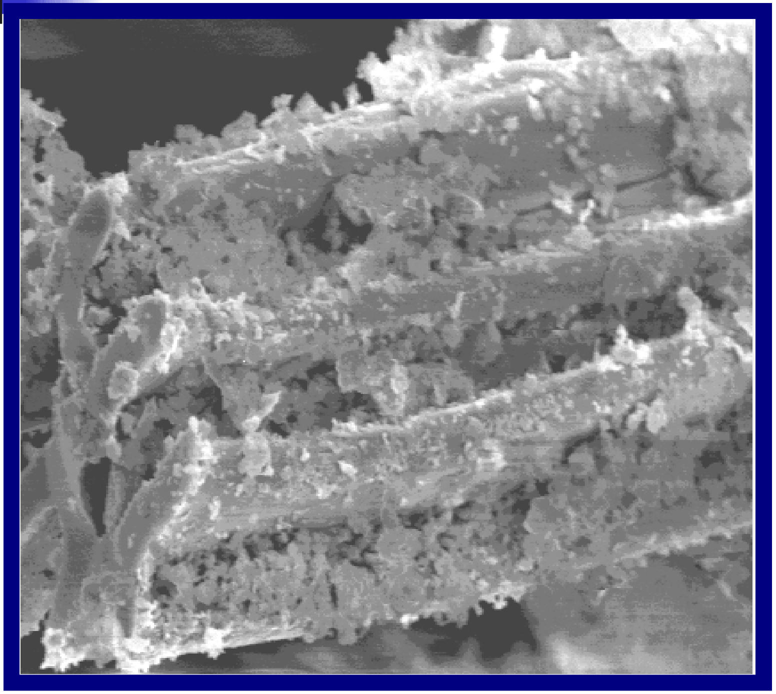




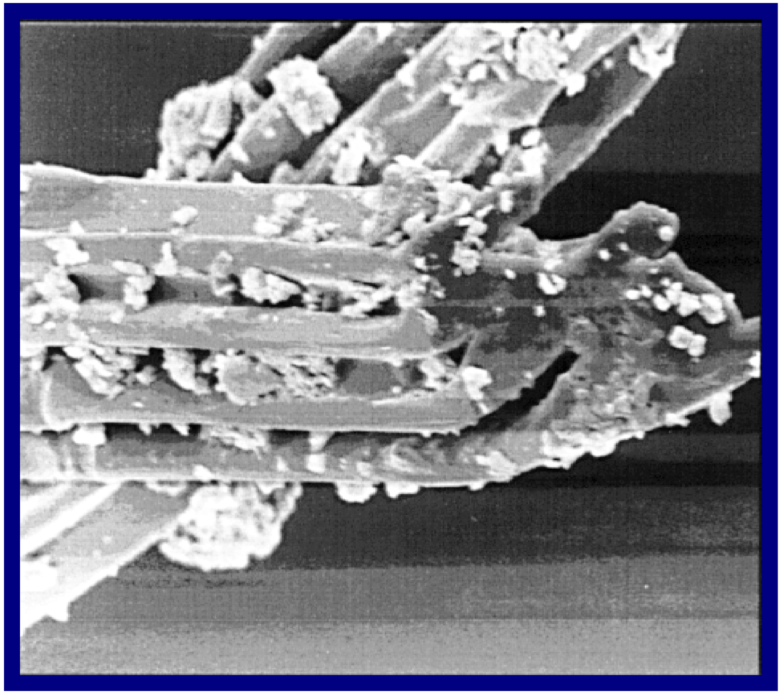
Properties

- Spontaneous wicking
- Dust trap
- Large surface area
- Better coverage
- Voluminosity

Deep grooves

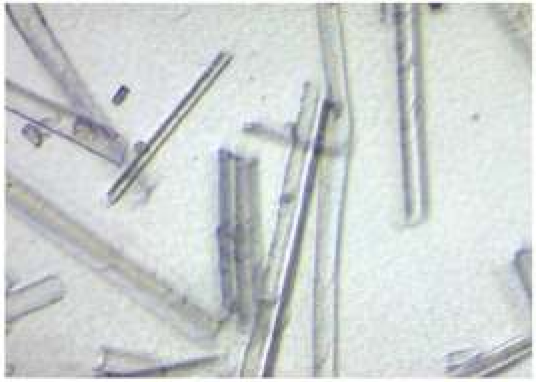


Dust trap



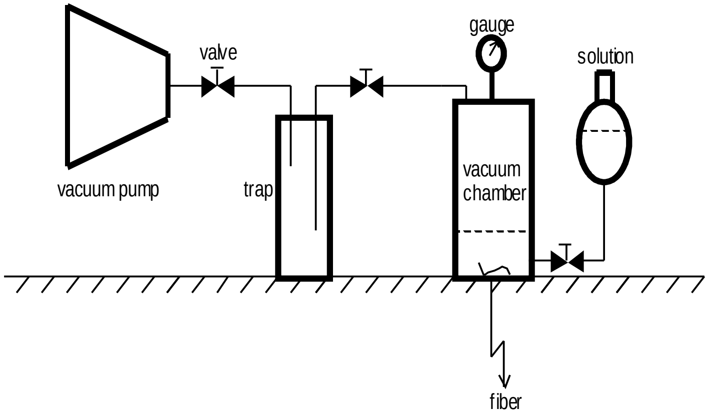
Anchoring of carbon particles (odour absorption)

Fibrous bioreactors

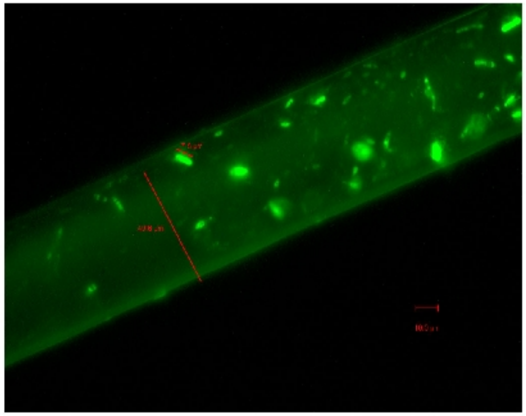


- Maintenance of live bacteria in fibres during sufficient time.
- Textiles removing oils and smudge, generating therapeutic agents.

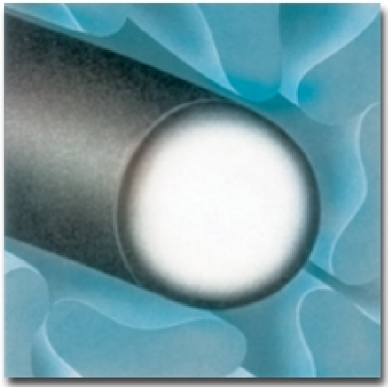
E. Coli and plasmid GFP-5 creating green fluorescent protein (GFP).

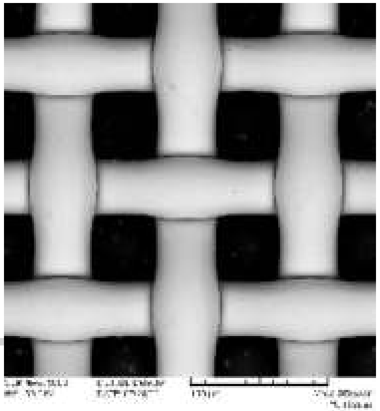


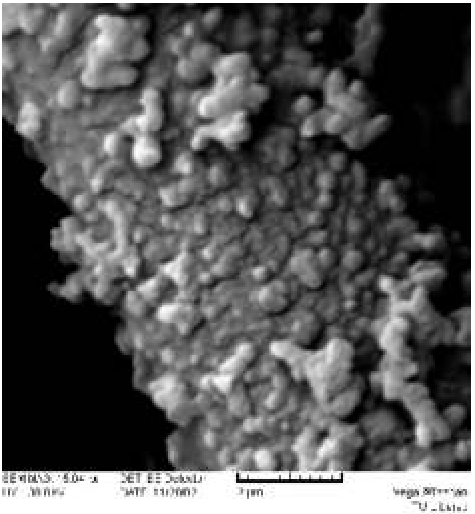
VPI System

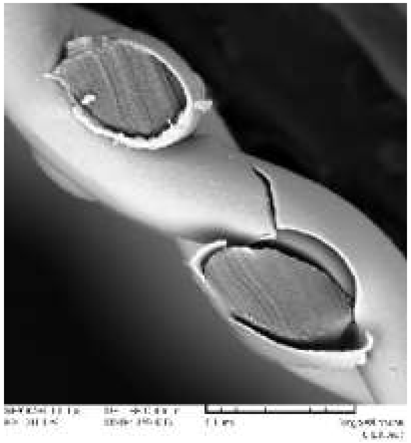


Surface Changes









- Metallisation „Mtex
- Controlled electro polymerisation PAN
- Polymer brushes

Hydrophility changes

molecular forest

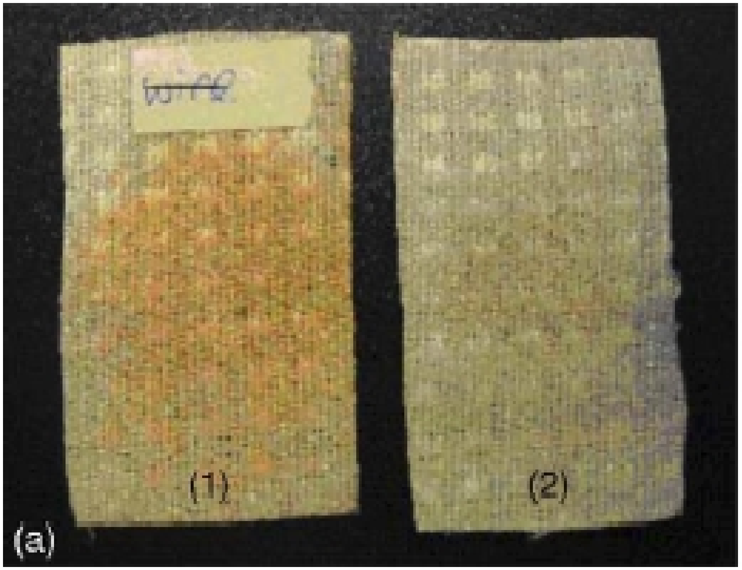
- Coating - Caffeine, sea algae extract, Activation of enzymes destroying fats. Fibres „wonder slim“ FUJI

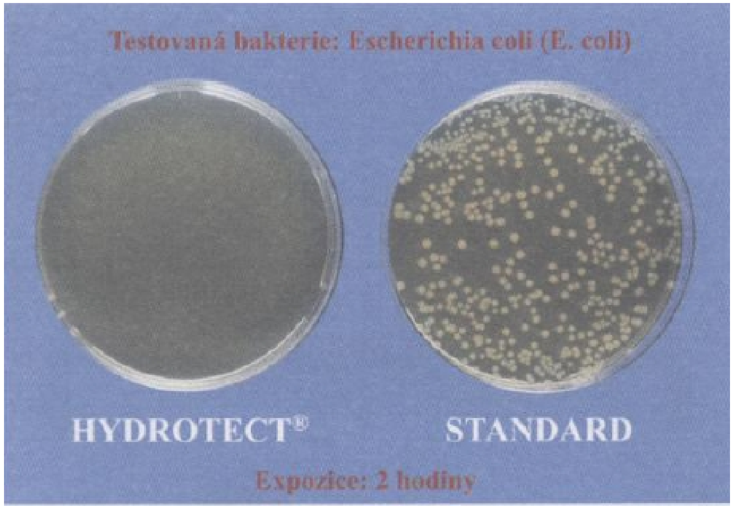
Self Cleaning Effect

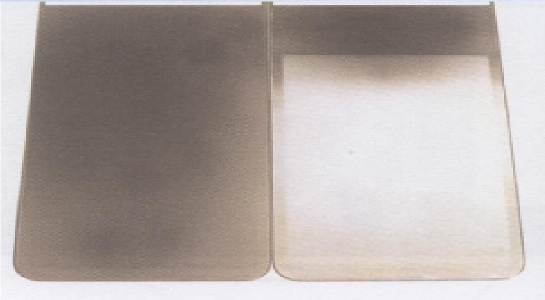
- Nano particles of TiO_2

  (anatase)
- Photocatalytic effect

  due to UV radiation
- Oxygen and hydroxyl free radicals - very active on small scale and in small time

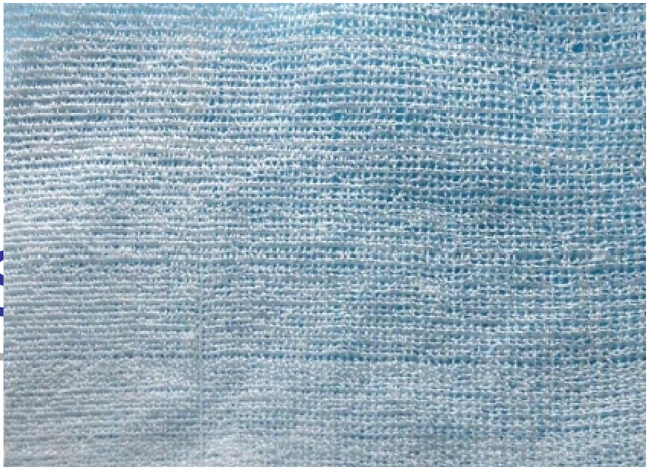




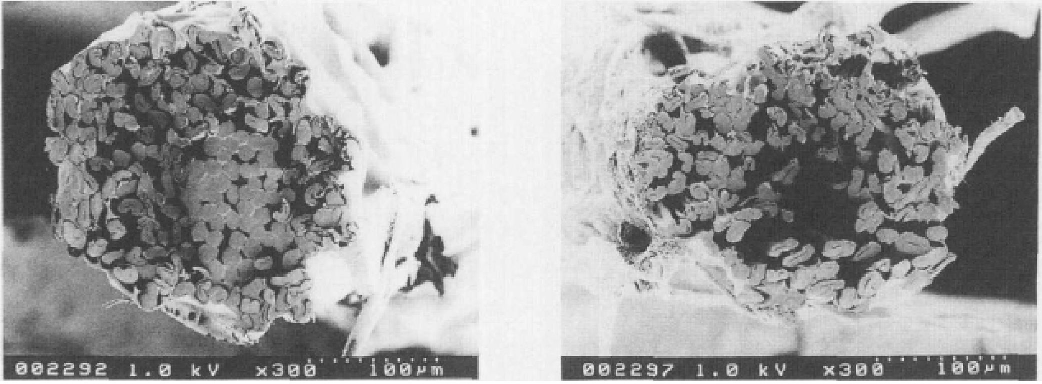


Textile products

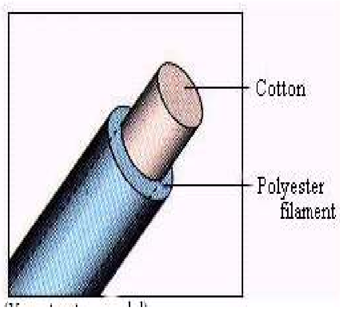
- Complicated hierarchical structure
- Cohesive secondary bonds
- Fractal surface
- Macro, micro and nano porosity

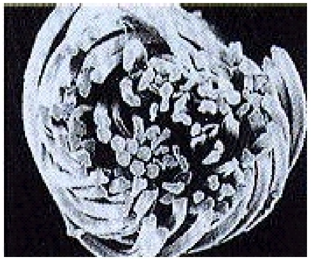


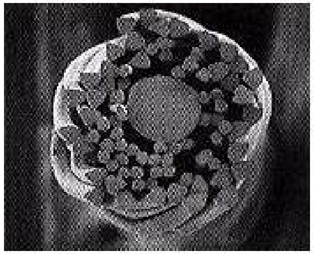
Specialty yarns



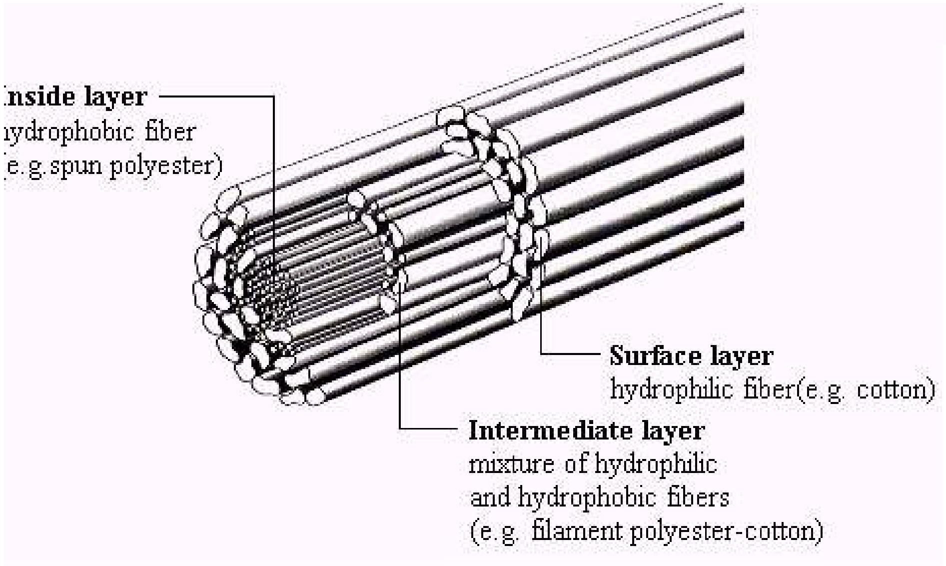
Hollow yarns

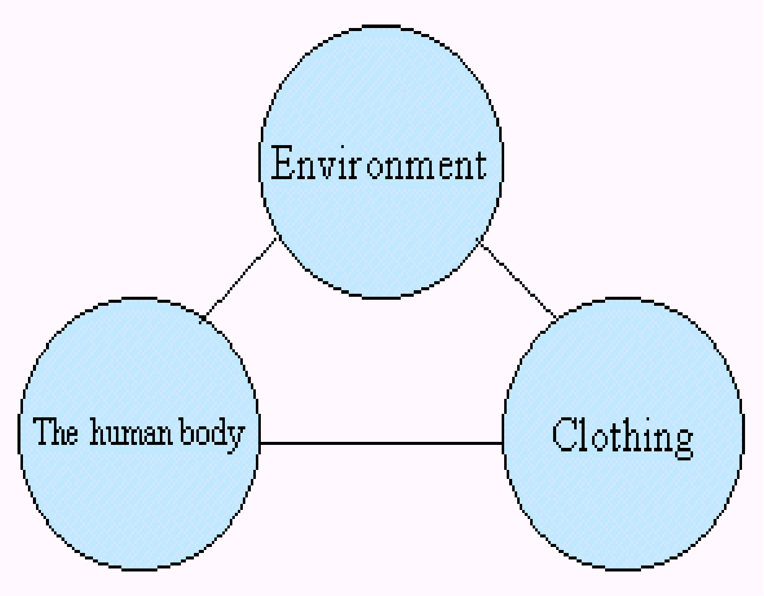






- Microclimate
- Quick sweat removal





Special nonwovens

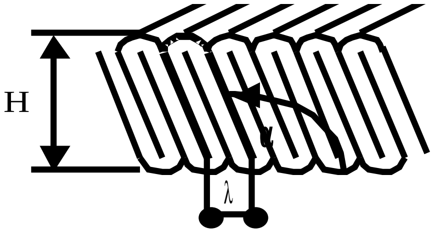
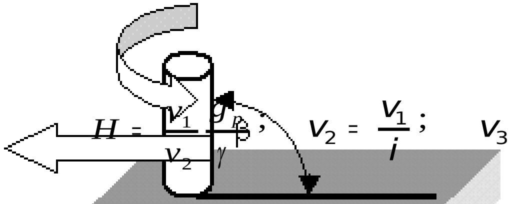


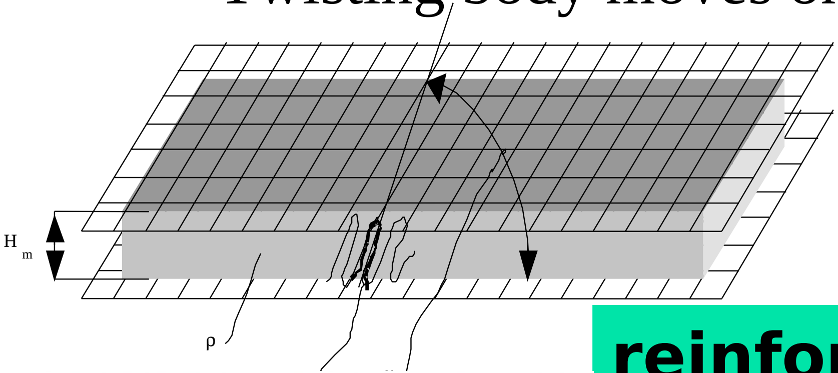
Fig.1



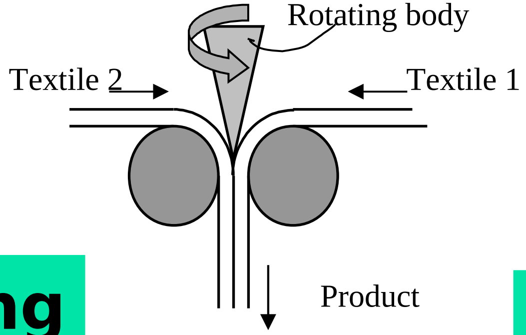
$H = \frac{v_1 g_p}{v_2 \gamma}$; $v_2 = \frac{v_1}{i}$; $v_3 = \frac{\rho}{}$

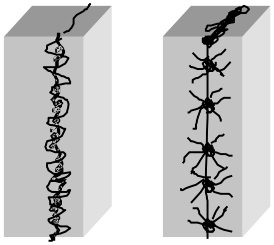
v_2 = output velocity of the conveyer 2 [m/s];
A = tooth pitch of the working roller 3 [m];
H = product thickness [m]; g_p= area weight o
γ = density of the product [kg/m^3] ρ = wave r
λ = length of the wave [m]

- Quasi-yarn is formed by twisting of fibre ends, which are protruding from the surface of textile material;
- Twisting body moves on the surface of a textile fabric.

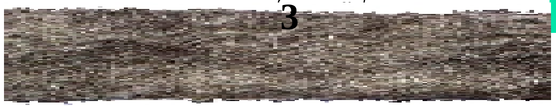


reinforcing

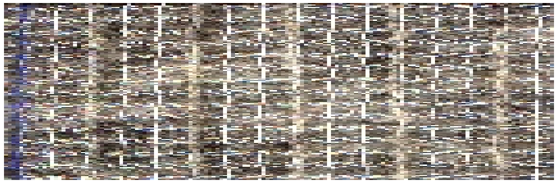


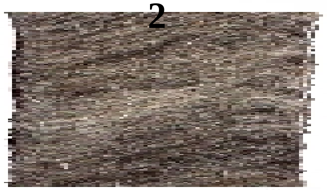


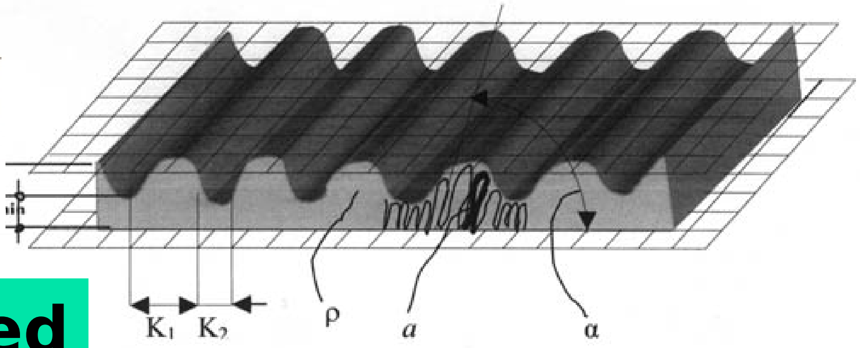
laminating



1







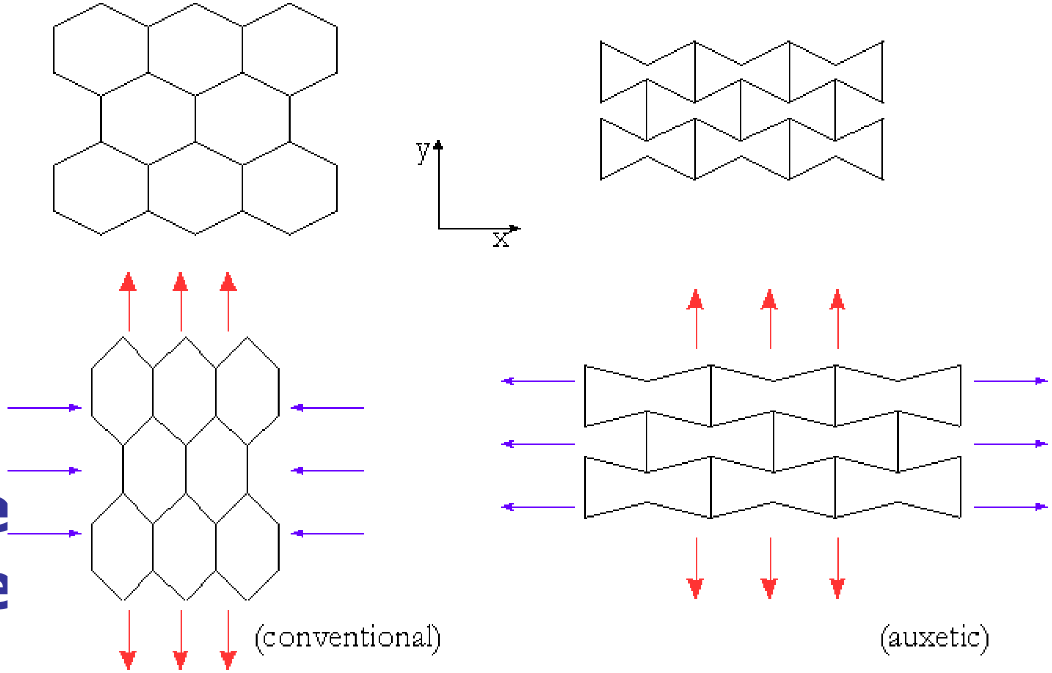
corrugated

$$\nu = \frac{lateral shrinking}{longitudinal\ \ extension} = -\frac{\varepsilon_T}{\varepsilon} \quad \text{where}\ \varepsilon_T = \frac{S - S_o}{S_o}$$

Auxetic structures

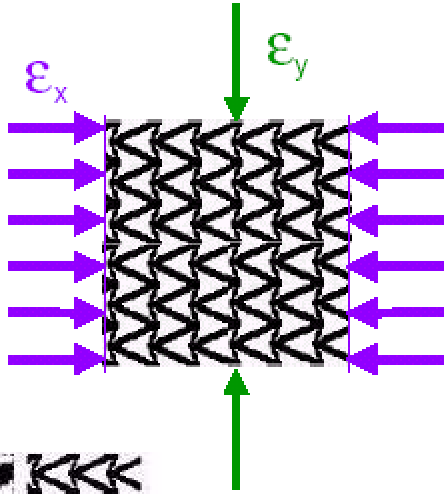
Auxetic **(enlarged). Negative Poisson ratio**

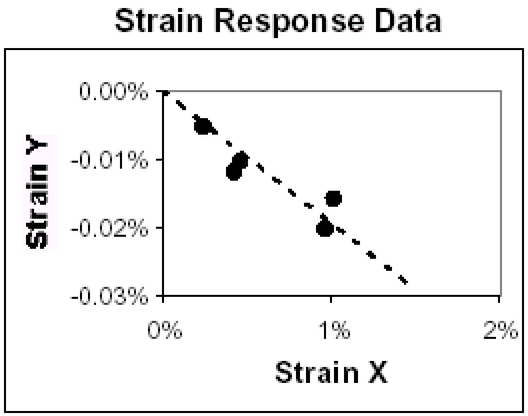
During the tensile deformation are extended laterally as well



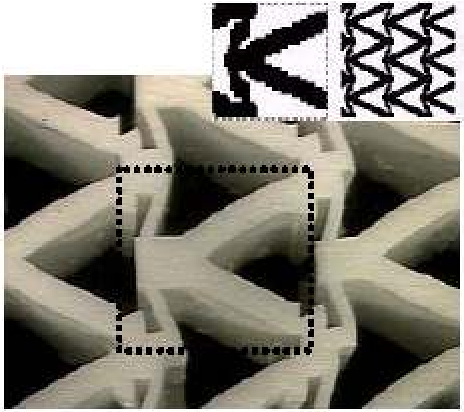
$$\frac{V}{V_o} = (1-\nu*\varepsilon)^2*(1+\varepsilon) \approx (1-2\nu)*\varepsilon$$

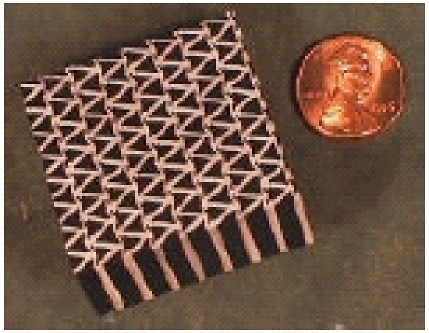
Auxetic structures II



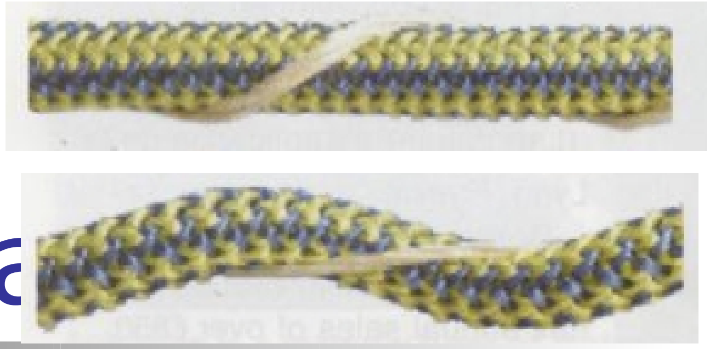


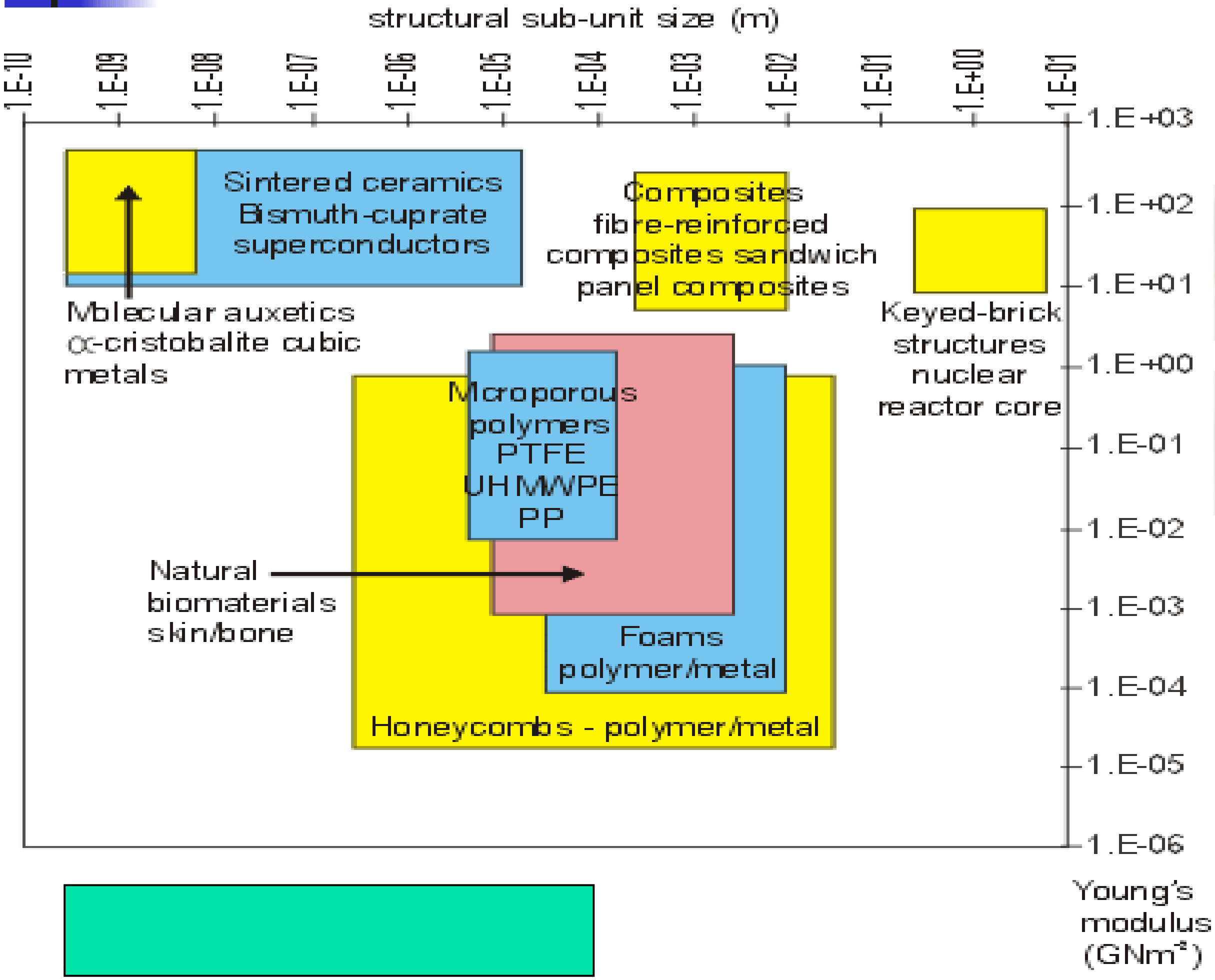
$$\upsilon = \frac{\varepsilon_y}{\varepsilon_x} = -0.02$$





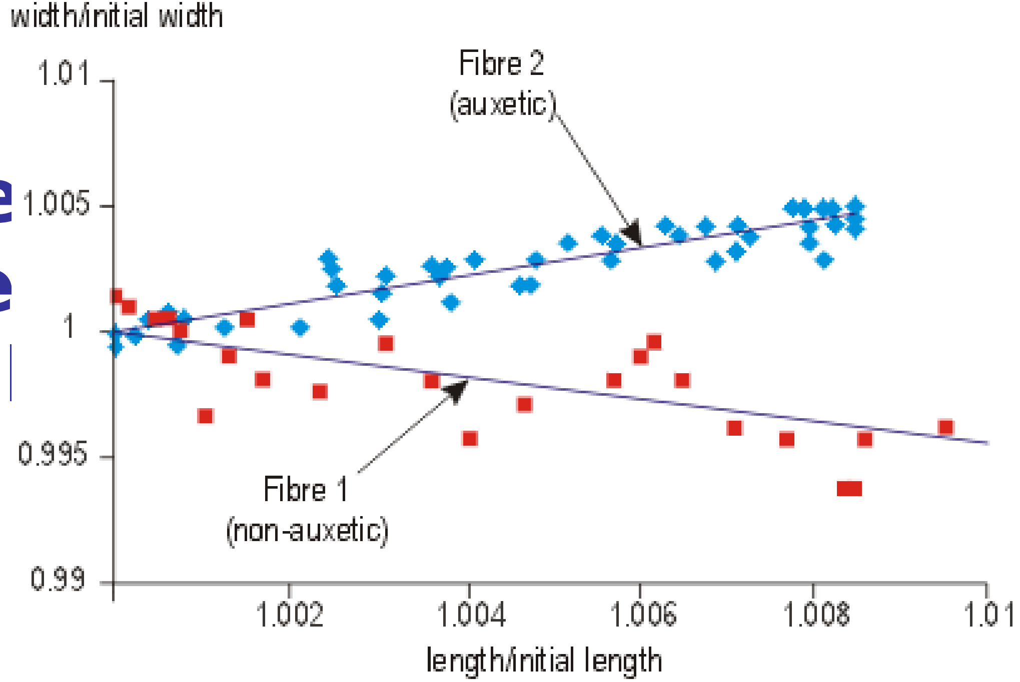
Auxetic materia



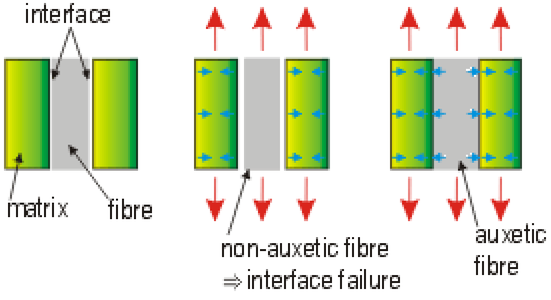


Auxetic yarn
PAD/cotton

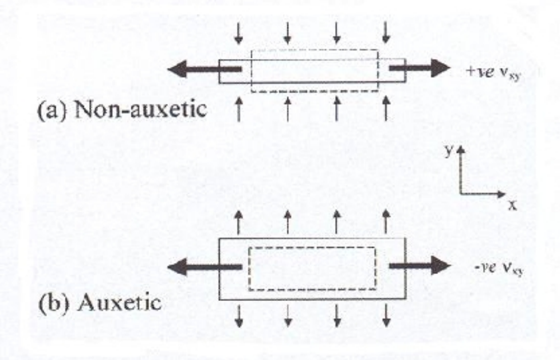
Auxetic polymers



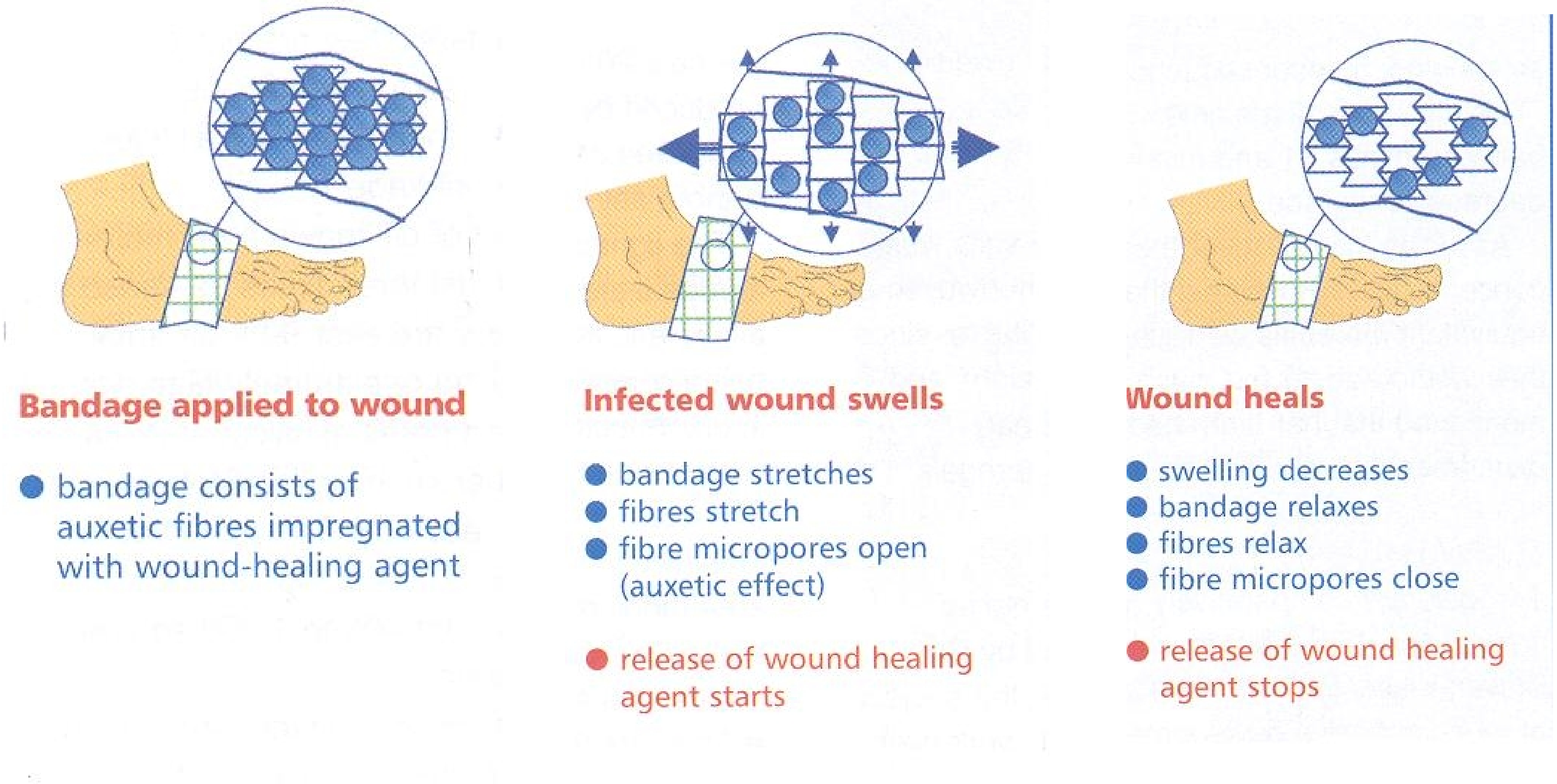
- **During the tensile deformation are extended lateral as well**



Azom.com™



Auxetic structures in medicine



Bandage applied to wound

- bandage consists of auxetic fibres impregnated with wound-healing agent

Infected wound swells

- bandage stretches
- fibres stretch
- fibre micropores open (auxetic effect)

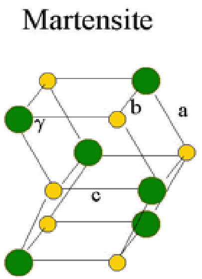
- release of wound healing agent starts

Wound heals

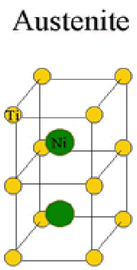
- swelling decreases
- bandage relaxes
- fibres relax
- fibre micropores close

- release of wound healing agent stops

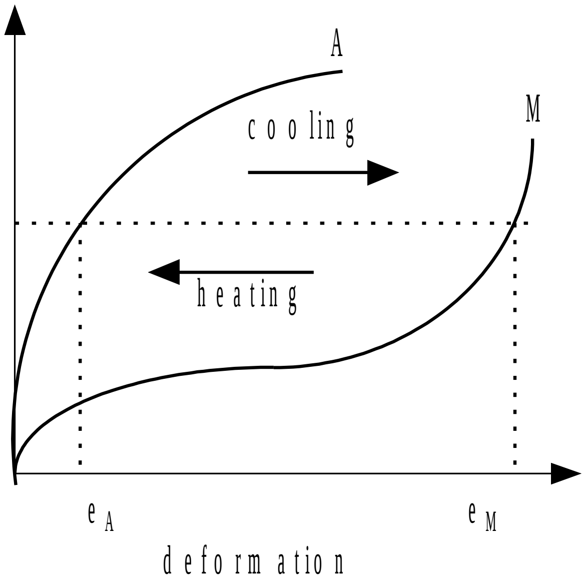
Shape memory alloys

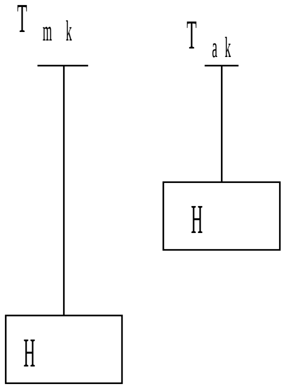


a, b, & c are not equal,
γ about 96°

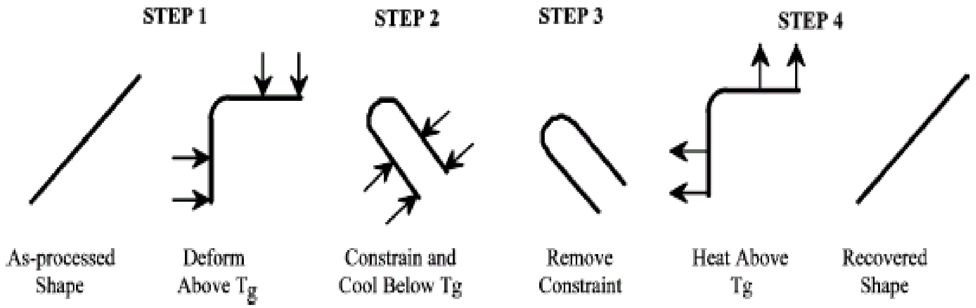


CsCl Structure
a = b = c
α = β = γ = 90°

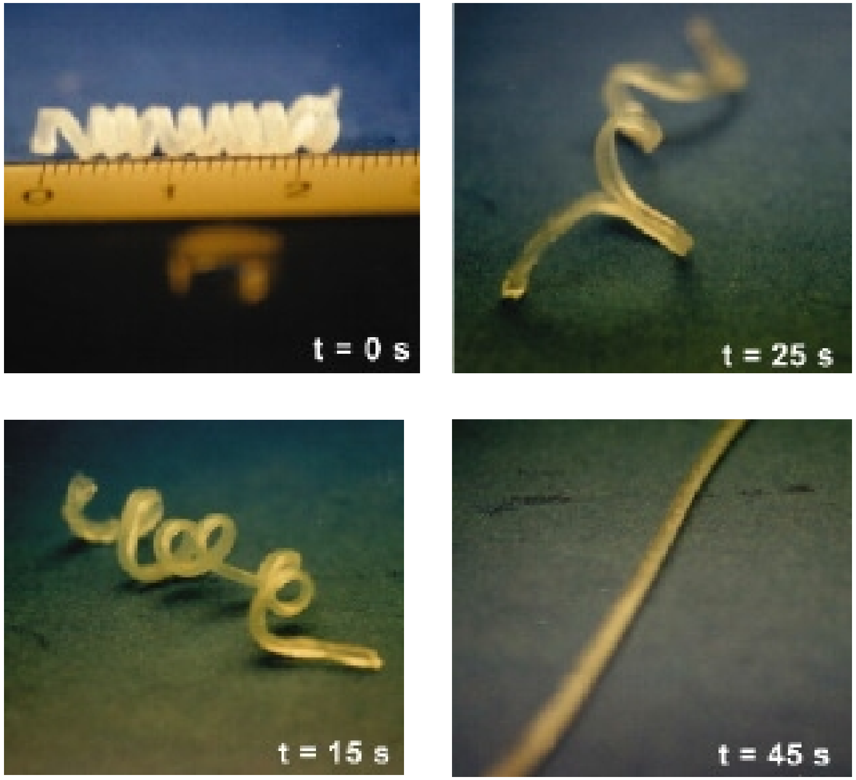




NiTiNOL- shape memory is due to phase changes in solid state.



Shape memory polymers

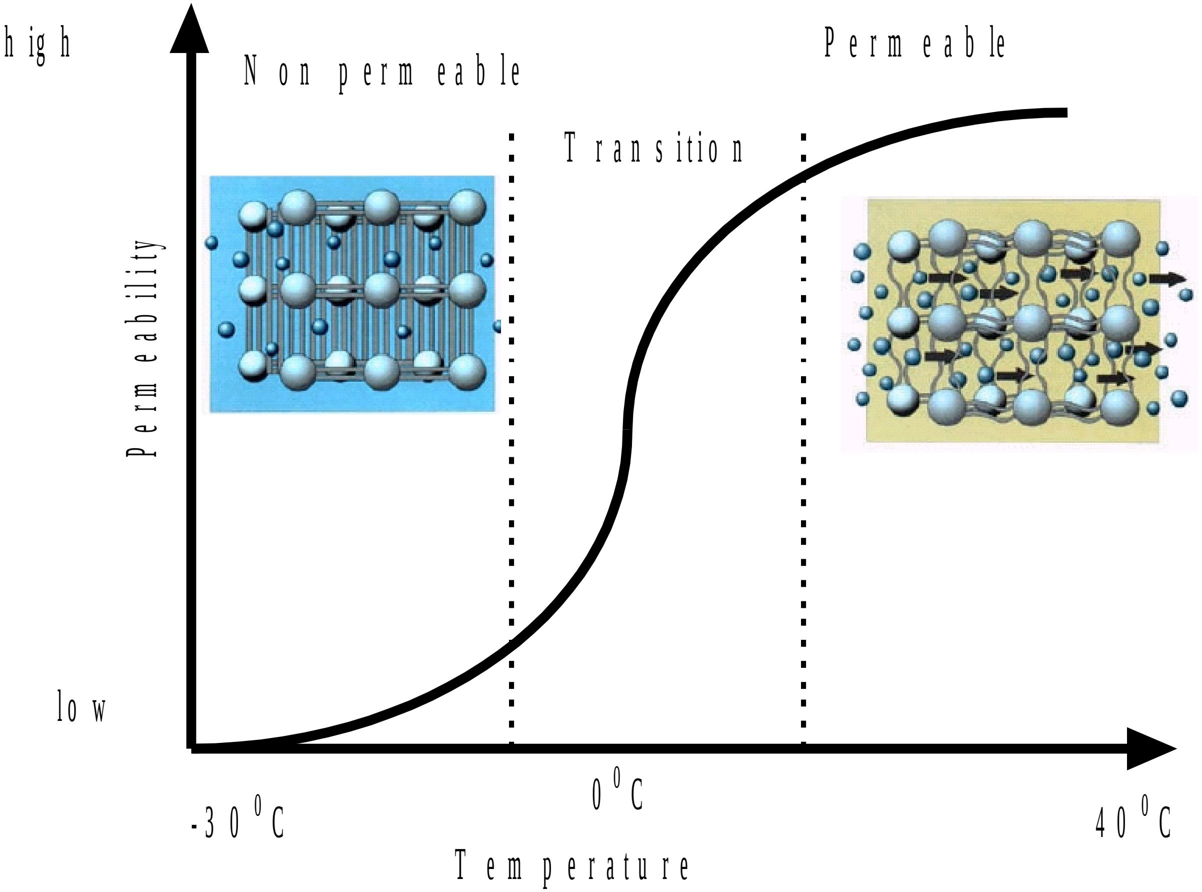


Recovery to original straight form

***Proc. Natl. Acad. Sci. USA*, 98, 842 (2001).**

Super elastic glasses

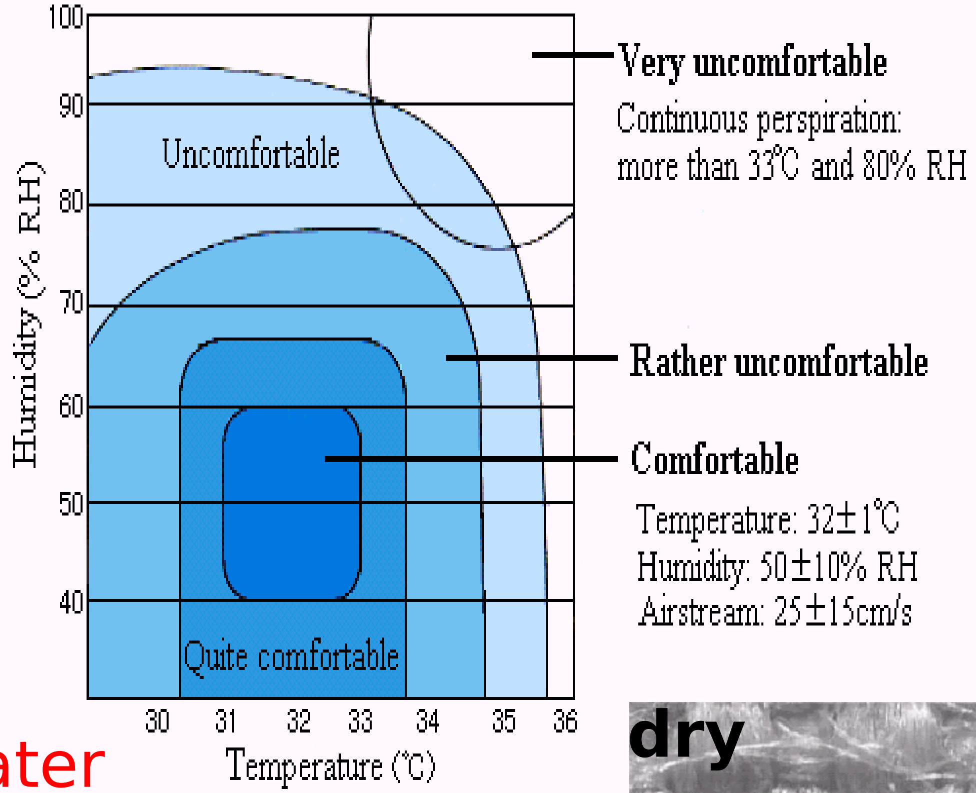
PUR membrane DiAPLEX



- **Air permeability is increasing due to body temperature increasing**
- **Below T_g is membrane non porous. Water from body is removed due to diffusion.**

Physiological comfort

- breathable
- Thermal insulation
- Ventilation
- No liquid sweat on skin



Very uncomfortable

Continuous perspiration: more than 33℃ and 80% RH

Rather uncomfortable

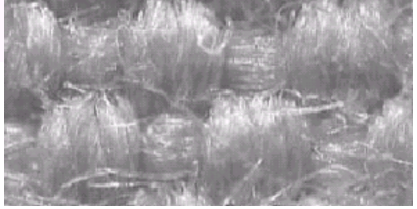
Comfortable

Temperature: 32±1℃
Humidity: 50±10% RH
Airstream: 25±15cm/s

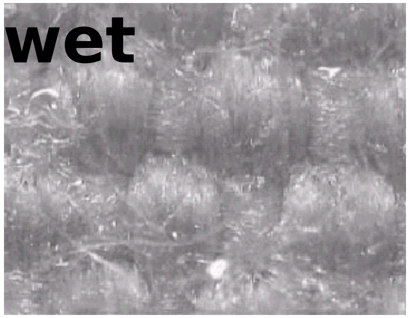
Non permeability for water – drop diameter 100 µm

Permeability for water vapour – molecule diameter 0.4 µm

dry

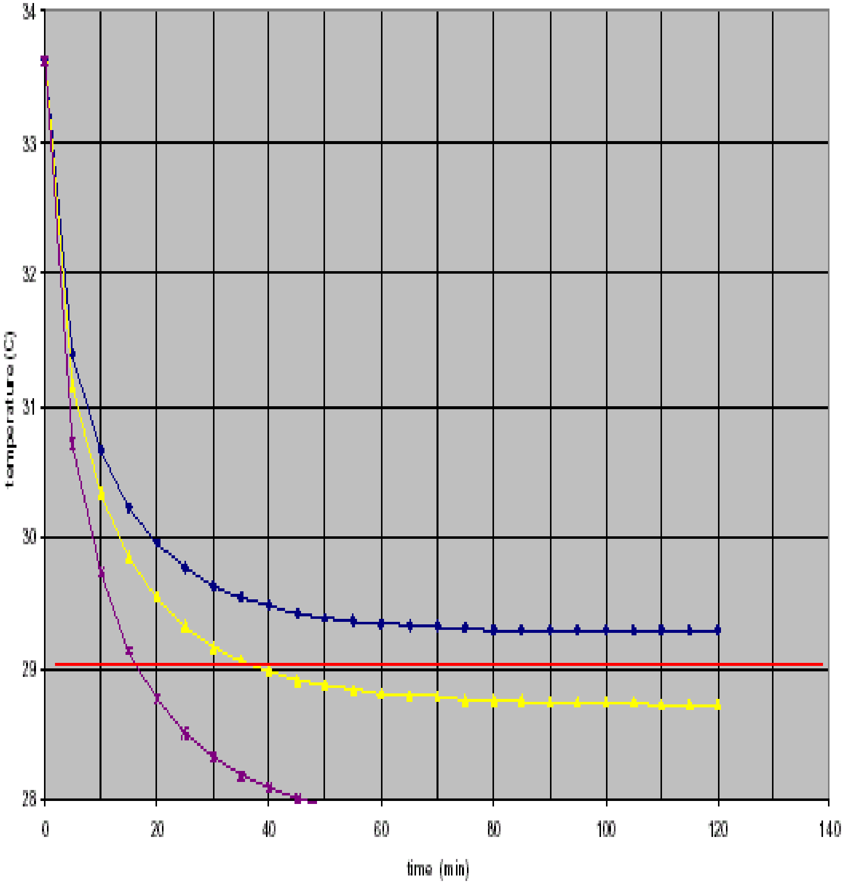


wet



1940 Ventile –fabric
Long staple cotton combed yarns
Oxford weave 2 ply yarn in warp
RAF

Thermal comfort


Mean Skin temperature Tsk
standing 160W - at 8 C in wind 8 m/s
TOLERANCE for MADRID and VIENNA

- Intensity of movement
- External conditions

1litreO_2/min = 20kJ/min

75-80% energy is heat

1 litre evaporated water = 2.4MJ

Middle endurance

1 litre oxygen per min

960 kJ heat per hour

Sufficient is to evaporate 400 ml sweat.

High endurance

4 litres oxygen per min

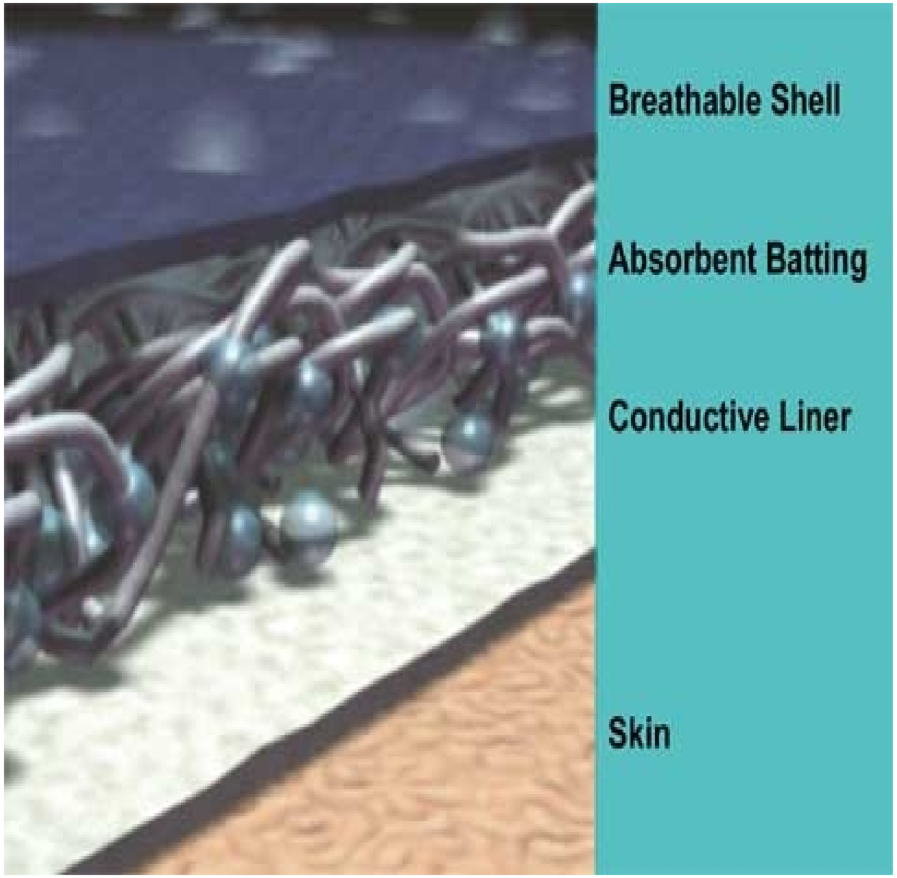
3600 kJ heat per hour

Evaporation oft 1500 ml potu. Limit

Thermal losses are increasing with square power of air velocity

Improved comfort

- Transport of water vapors
- Non permeability for liquid water
- Air exchange
- Thermal insulation



Thermal effects

- **Heat evolved by phase change**

$$Q = m * L = V * \rho * L$$

m mass, latent heat ***L*** [kJ/kg] boiled water 2256

- **Heat evolved by heating**

$$Q = m * c * \Delta T = V * \rho * c * \Delta T$$

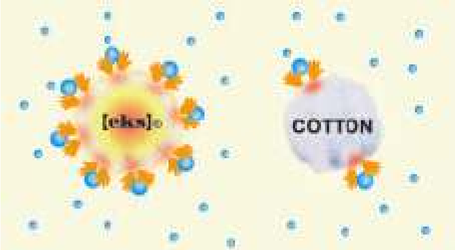
Specific heat ***c*** [J/(kg K)] water 4190

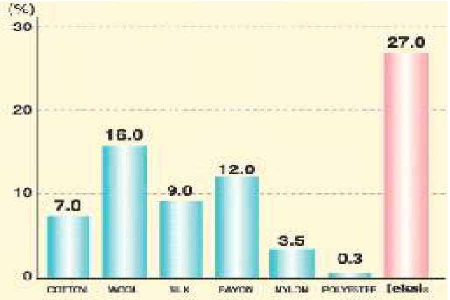
- **Heat evolved by conduction**

$$\frac{Q}{t} = \lambda * A \frac{\Delta T}{h}$$

λ [W/(m K)] thermal conductivity: air 0.026 water 0.68 skin 0.09 PES 0.2 Ag 428, ***A*** area, ***t*** time, ***h*** thickness

Heat energy storing





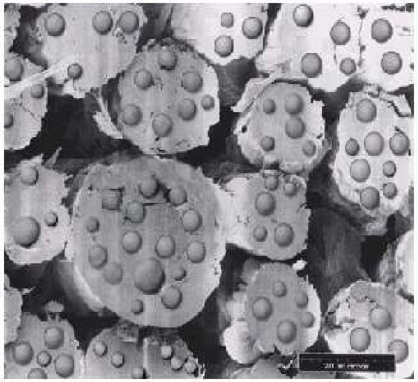
- Temperature sensitive materials. Water from 1 ℃ to 99 ℃. Increasing temperature (1 ℃), absorption of heat 4,18 J/g.

(fiber EKS Toyobo cross linked polyacrylate).

- Phase change materials Storing and releasing of heat as a result of phase changes (solid –liquid). Short time effect., PEG has latent heat of phase change L = 121 J/g

Heat storing- Outlast

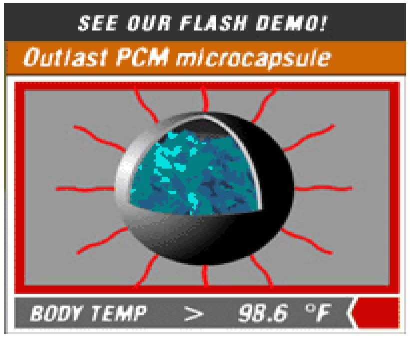
- Encapsulation of liquid crystalline

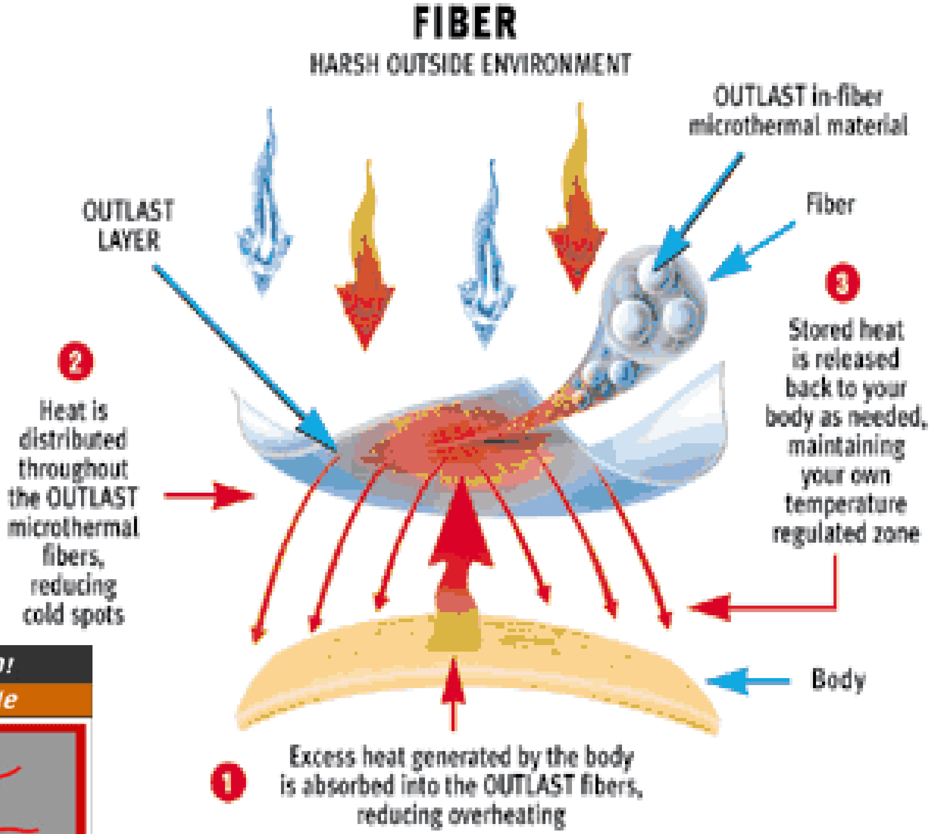


PCM

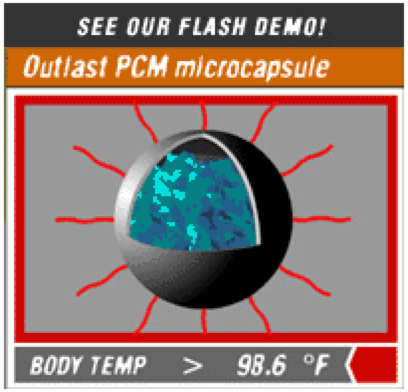
phase changin

materials





Time to phase change



- Encapsulated (PEG) have no influence to heat transfer. Their volume ratio is v_f ,density H_m=1500 kg m^{-3} and latent heat of phase change is L=121 J g^{-1}
- Capsules are dispersed in PET matrix of thickness h=1 mm and thermal conductivity $\lambda = 0{,}2$ W $m^{-1}K^{-1}$
- Temperature difference between inner and outer layer is dT= 5K

$$t[s] = \frac{h^2 * v_f * H_m * L}{\lambda * dT}$$

For v_f =0.3 is result t = 54.4 s.

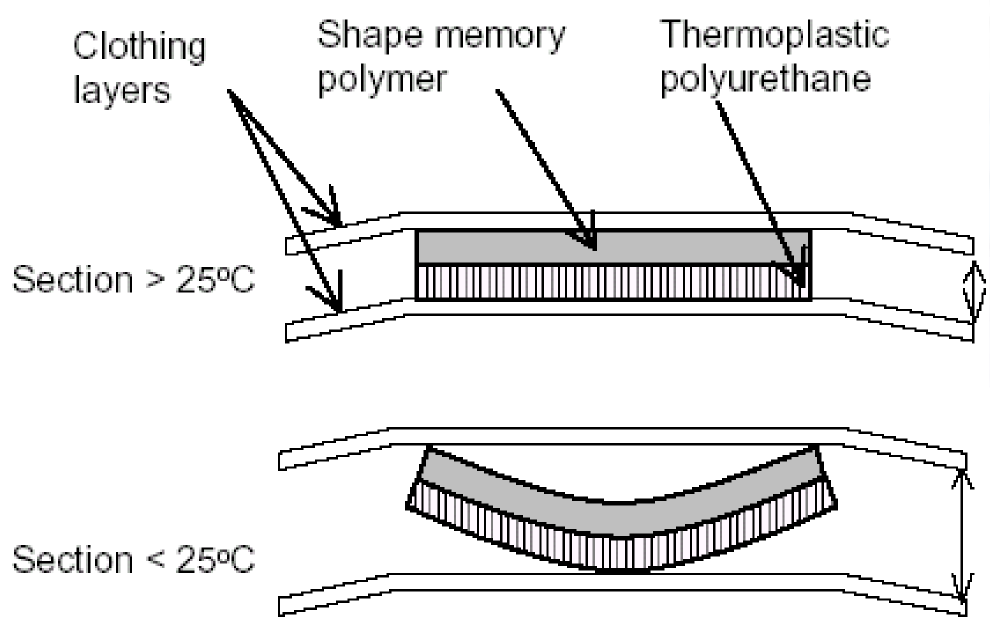
Active cooling

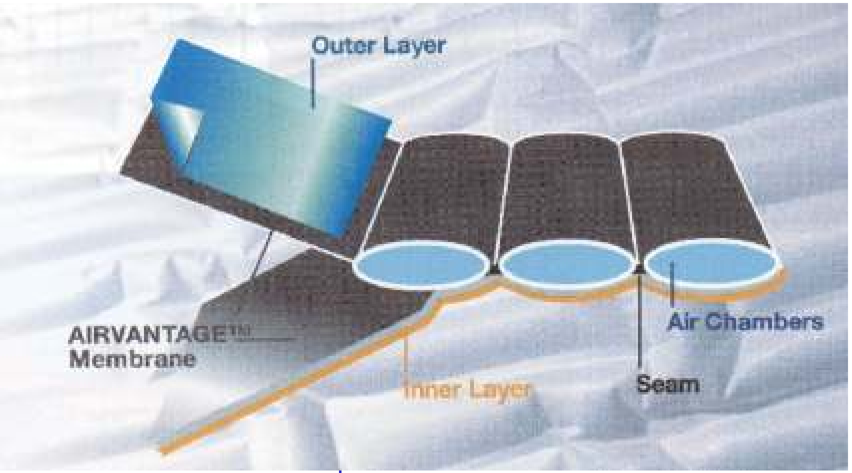
- Space suits – active cooling by circulation of water in pipes

  D´Appolonia adopted this system for apparel applications.
- PCS- Personal cooling system CSIRO. Heat transfer via thermal exchange tube (exchanger based on cooling by evaporation).

Thermal insulation

Material	Thermal Resistance (Km²/w)/mm
Polyester (hollofill)	0.0151
Polyester (microfibres)	0.0320
Polyester (split-fibres)	0.0473





Active thermal adaptation

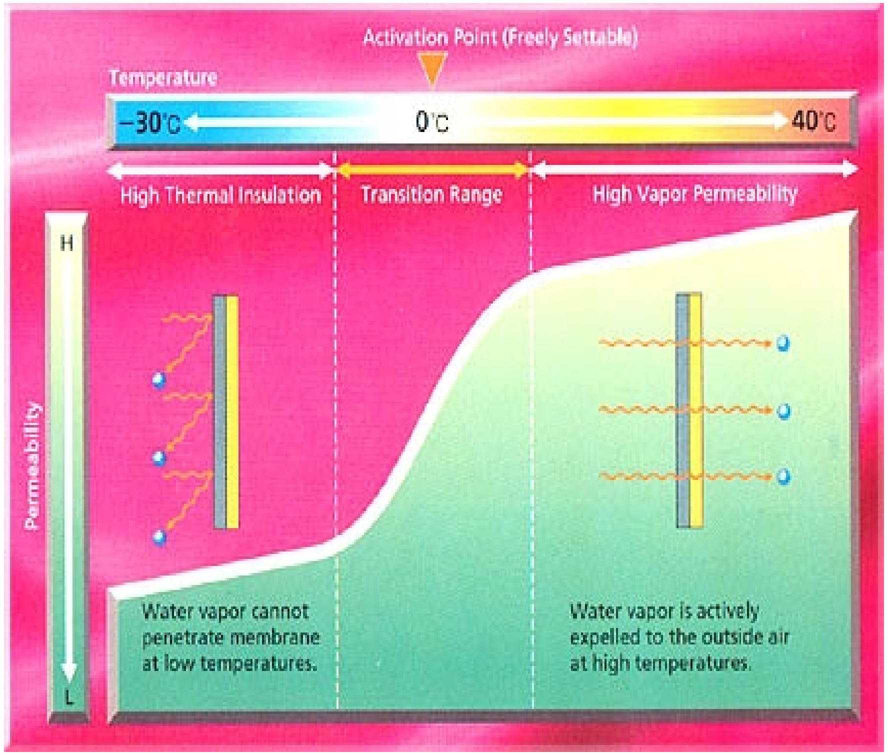
- <u>Shape memory</u>

(reversible form changes due to heating and cooling)

- <u>Variable porosity and water vapor permeability</u>

SSM membranes

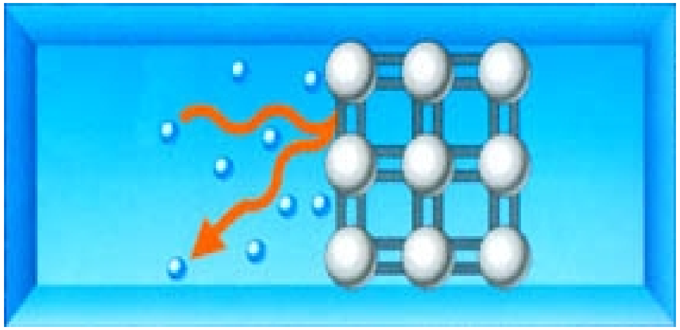
Sensitive to temperature changes



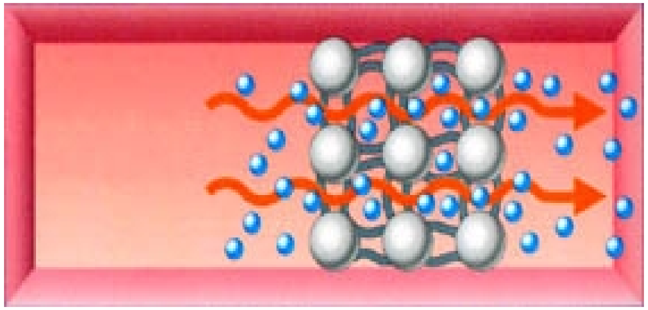
Water vapor cannot penetrate membrane at low temperatures.

Water vapor is actively expelled to the outside air at high temperatures.

Low temperature

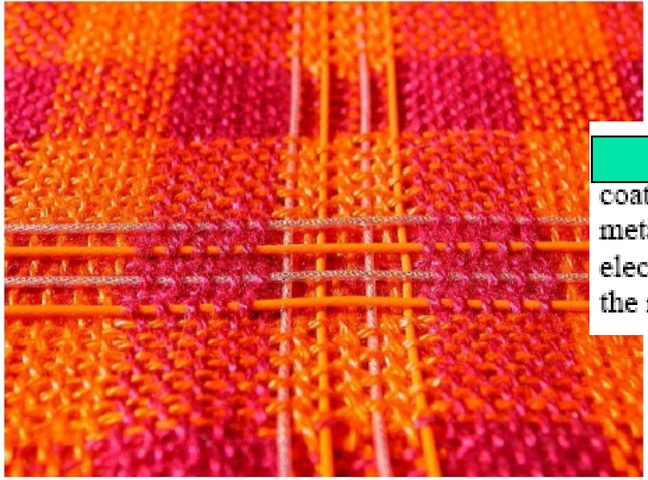


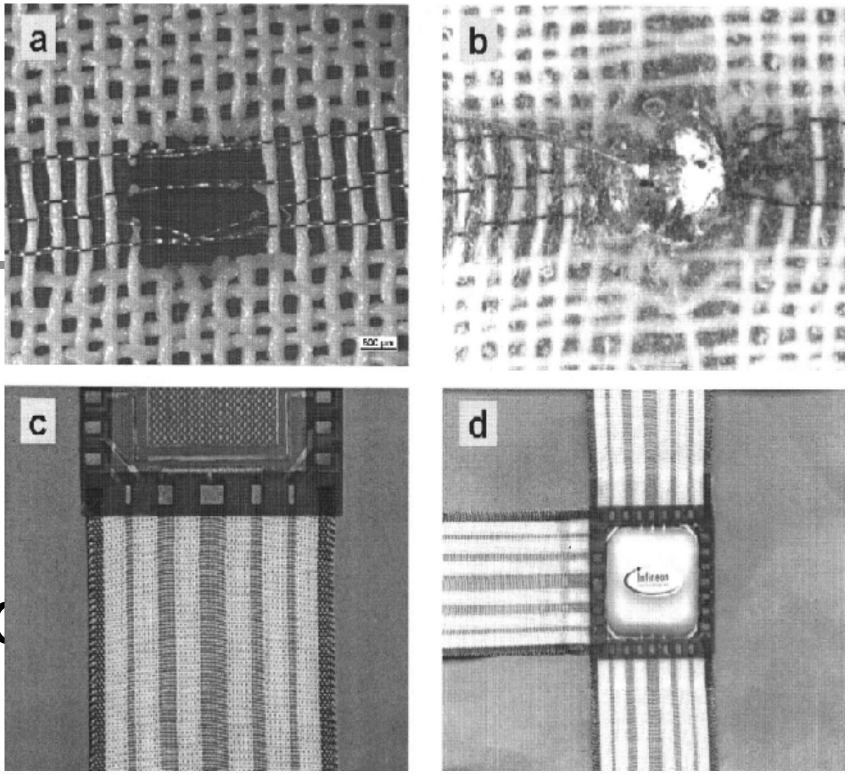
High temperature



Passive intelligence

Special kind of passive intelligent structures are parts of wearable electronics and wearable computers





Microphotographs of interconnect experiments performed on a woven test ribbon. (a) The coating of the wires is removed by laser treatment. (b) The woven wires are soldered to a small metal foil and connected to an electronic circuit by a thin wire. (c) Alternatively, the contact to an electronic module can be established via a flexible circuit board soldered to the ribbon. (d) Finally, the module and the contact areas are molded.

Wearable electronics I

ANBRE (analogue biomechanical recorder)

Spots on the body for including electronic parts.

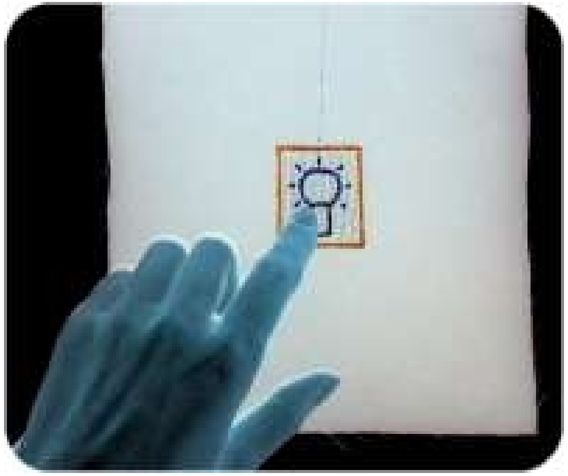
(designer view)

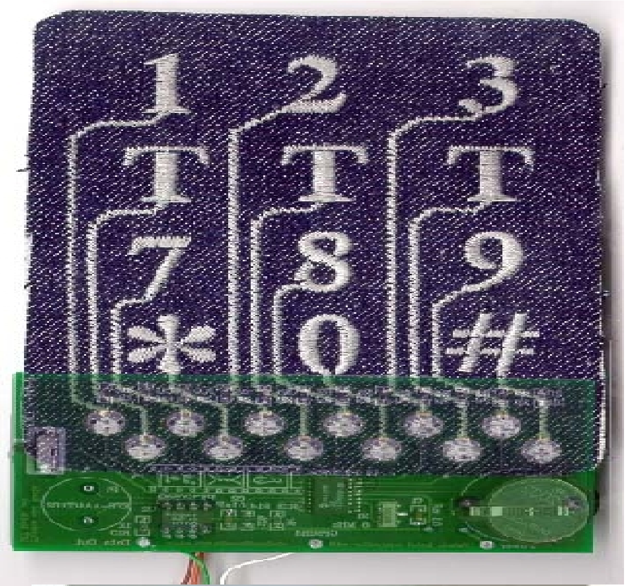
Wearable electronics II

E-TAG AND SWEATER SNAP CONNECTIONS

Music jacket

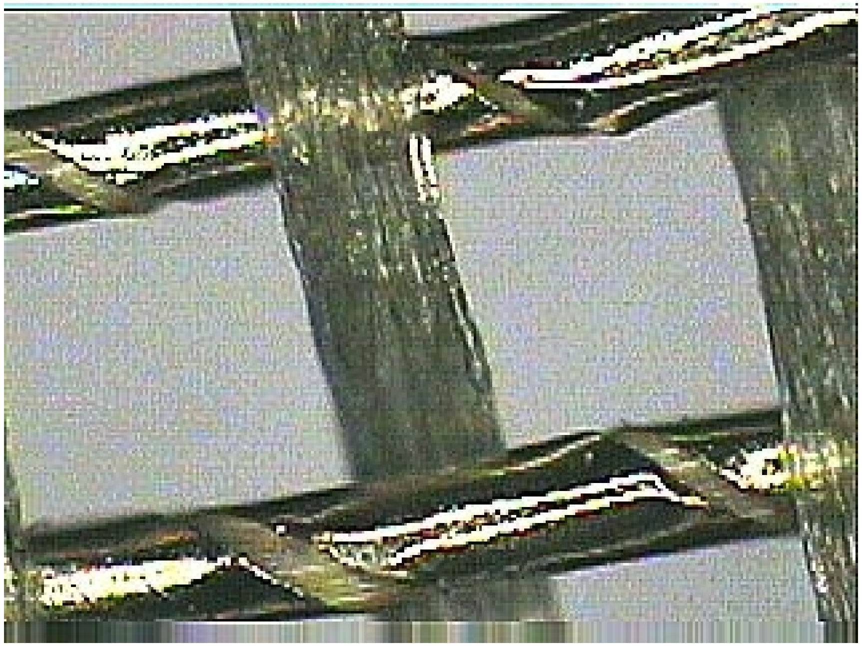
Textile switches





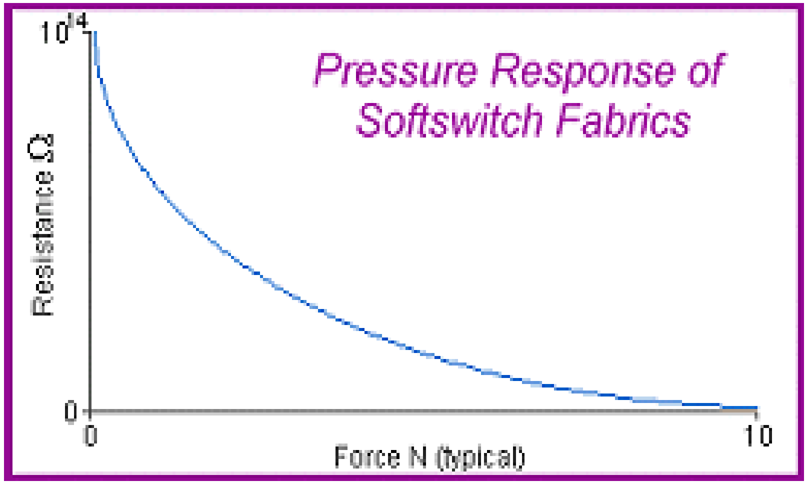
Textile keyboards

- Conductive net



Pressure sensors

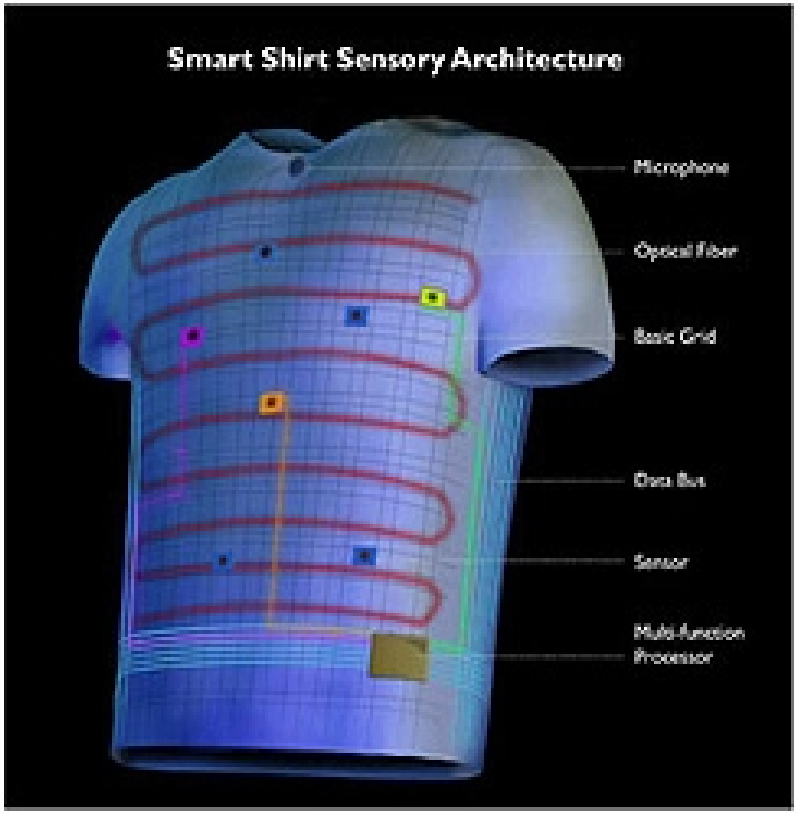
- Soft switch



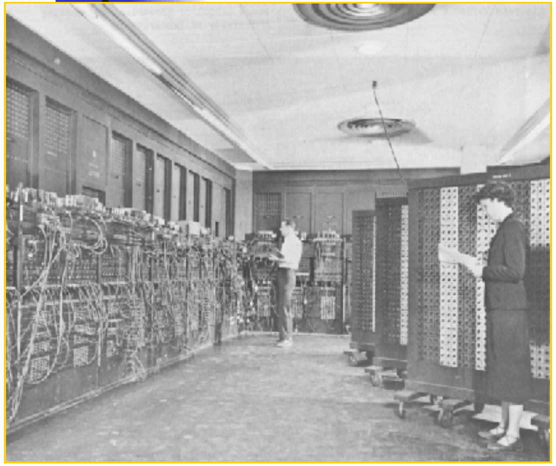
Inteligent shirt

- Electronic devices
- Heart rate
- Breathing
- Body temperature
- Electrocardiogram
- Voice

Weave with optical fibers net

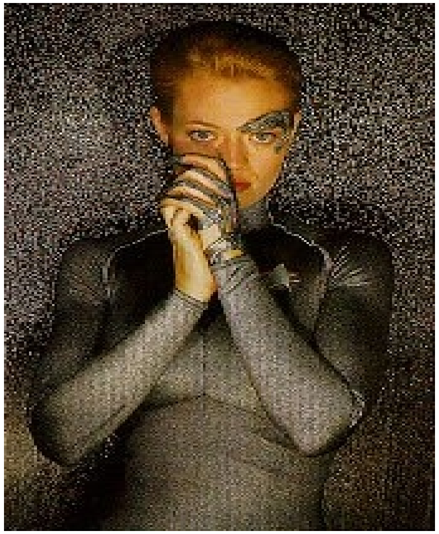


Computers development



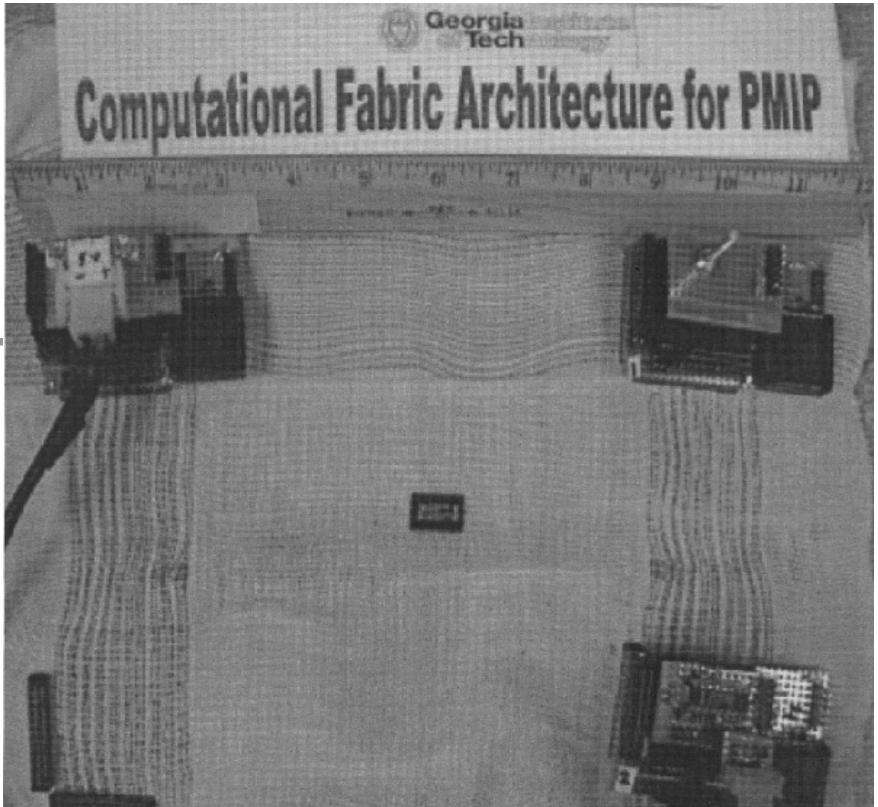
Past times

Today reality



Wearable computers

1. Parts on the body and cloth
   - Inteligent shirts
1. Intuitive interface
   - Speech and movement recognition
1. Visual communication
   - Transparent Display
1. New sensations (IR sonar)
2. Proactive (ready to work immediately)




CharmIT Wearable Computer

- 266MHz Intel Pentium or 800MHz Transmeta Crusoe

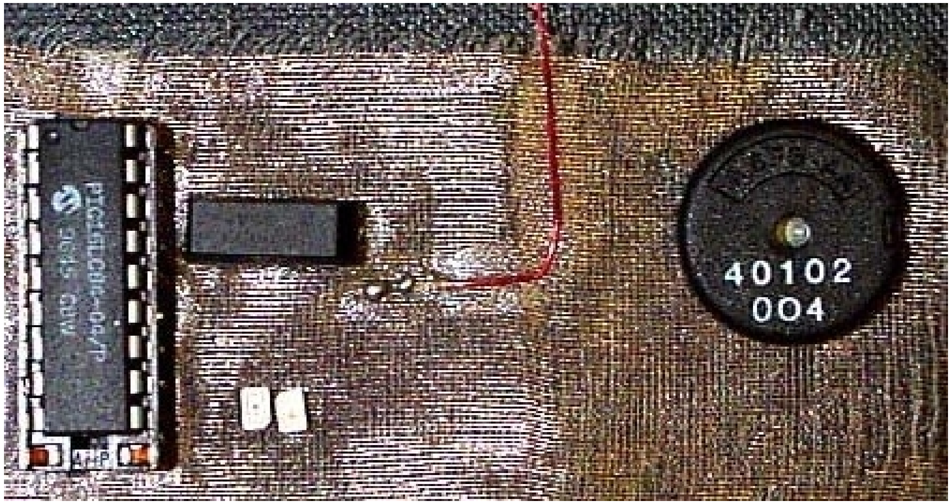
July 3, 2000

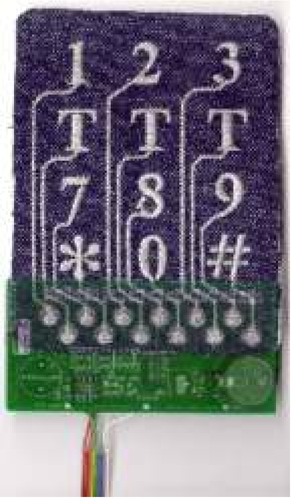
Greg Priest-Dorman
gpriest-dorman@charmed.com

Textile computer MIT

- washable
- flexible

MIT ,Textile computer





Computer comfort

Hard computers

- hard
- stiff
- thick

Textile computers

- soft
- flexible
- thin

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