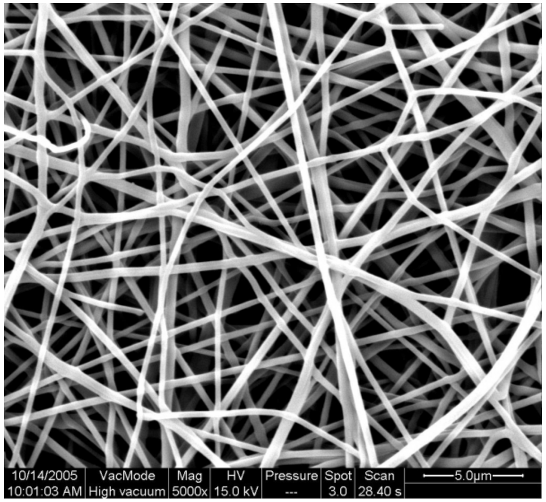
Nano fibre production and improving the functionality



Nanofiber

Botanists - elongated, thick-walled cells that give strength and support to plant tissue.

Anatomists understand "fibers" as any of the filaments constituting the extracelullar matrix of connective tissue, or any of various elongated cells or threadlike structures, especially muscle fiber or nerve fiber.

The textile industry views fibers as natural or synthetic filament, such as cotton or nylon, capable of being spun into yarn, or simply as material made of such filaments.

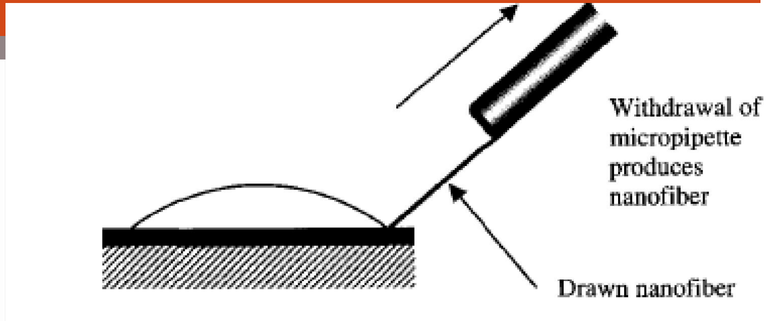
Nanofiber
A nanofiber is a nanomaterial in view of its diameter, and can be considered a nanostructured material if filled with nanoparticles to form composite nanofibers.

1-dimensional nano-scale elements that includes nanotubes and nanorods.

Drawing

Nanofibers have been fabricated with citrate molecules through the process of drawing.

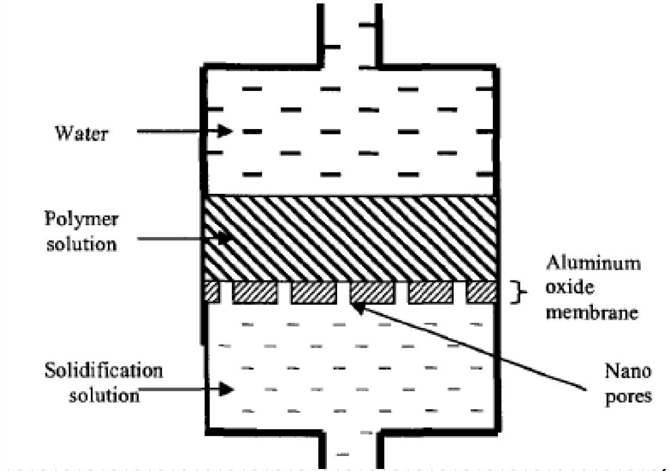
A micropipette with a diameter of a few micrometers was dipped into the droplet near the contact line using a micromanipulator



The micropipette was then withdrawn from the liquid and moved at a speed of approximately 1×10^{-4} ms-1, resulting in a nanofiber being pulled.

Template Synthesis

Under the application of water pressure on one side and restrain from the porous membrane causes extrusion of the polymer which, upon coming into contact with a solidifying solution, gives rise to nanofibers whose diameters are determined by the pores.

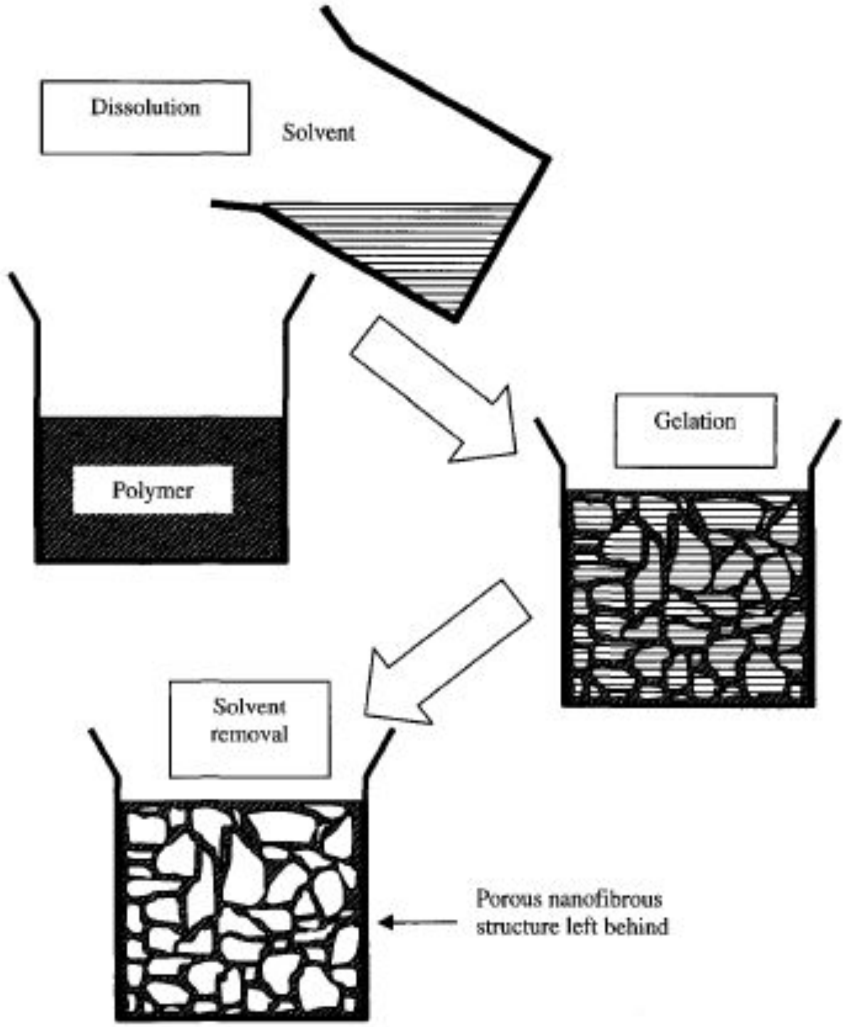


Phase Separation

In phase separation, a polymer is firstly mixed with a solvent before undergoing gelation.

One of the phase - which is that of the solvent - is then extracted, leaving behind the other remaining phase.

(i) polymer dissolution,
(ii) gelation,
(iii) solvent extraction,
(iv) freezing and
(v)freeze-drying



Electrospinning

Electrospinning is a process that creates nanofibers through an electrically charged jet of polymer solution or polymer melt.

The electrospinning process, in its simplest form consist of a ***pipette to hold the polymer solution, two electrodes and a DC voltage supply in the kV range***

The polymer drop from the tip of the pipette was drawn into a fiber due to the high voltage.

The jet was electrically charged and the charge caused the fibers to bend in such a way that every time the polymer fiber looped, its diameter was reduced.

Important features of electrospinning are:

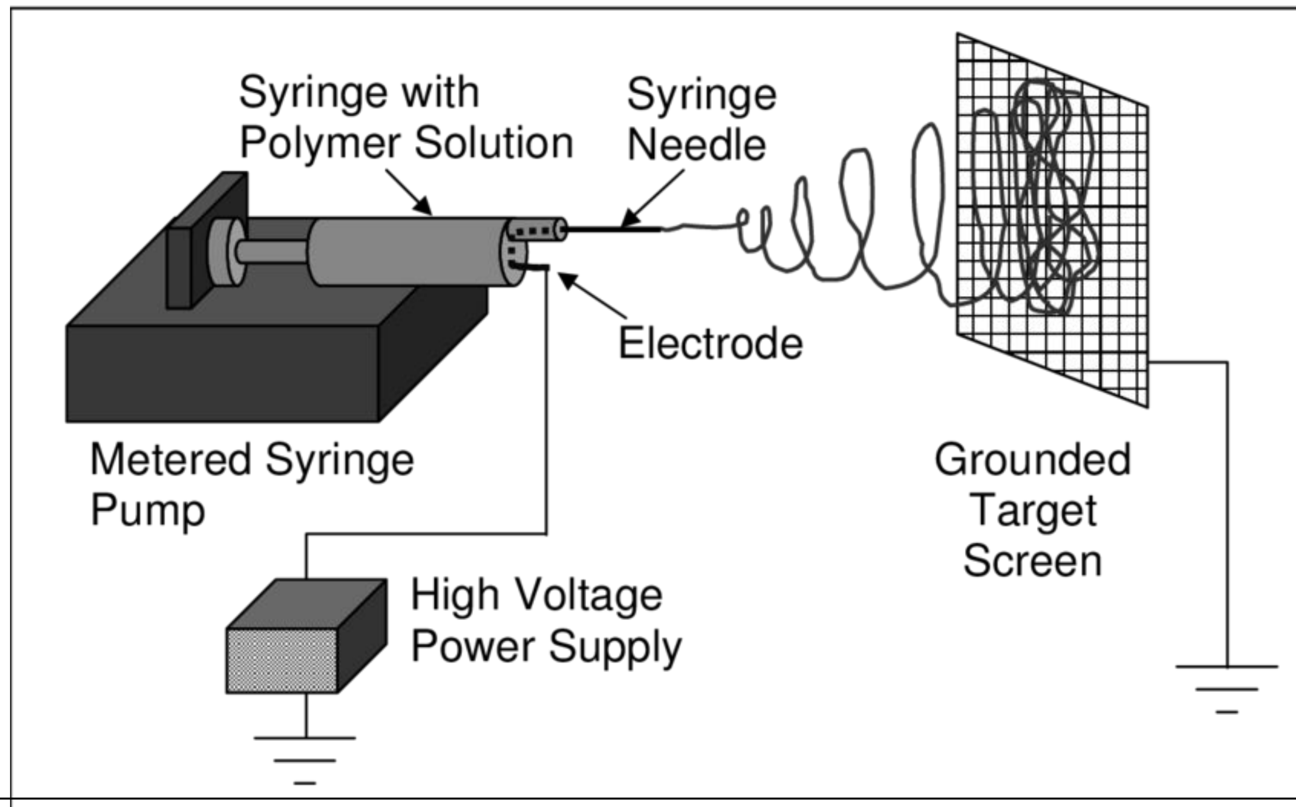
• Suitable solvent should be available for dissolving the polymer.

• The vapor pressure of the solvent should be suitable so that it evaporates quickly

The viscosity and surface tension of the solvent must neither be too large nor be too small
The power supply should be adequate to overcome the viscosity and surface tension of the polymer solution

The gap between the pipette and grounded surface should not be too small but should be large enough for the solvent to evaporate in time for the fibers to form.

ESPIN - NANO
WARNING
DANGER
HIGH
VOLTAGE



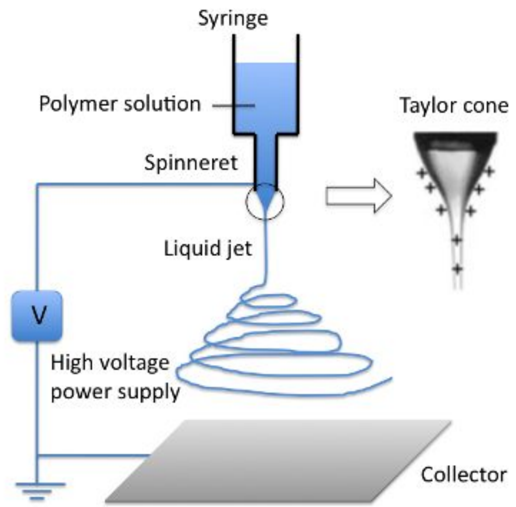
Syringe with
Polymer Solution
Syringe
Needle
Electrode
Metered Syringe
Pump
Grounded
Target
Screen
High Voltage
Power Supply

Elecrospinning

- In electrospinning, a high voltage is applied to a polymer fluid such that charges are induced within the fluid.
- When charges within the fluid reached a critical amount, a fluid jet will erupt from the droplet at the tip of the needle resulting in the formation of a Taylor cone.
- The electrospinning jet will travel towards the region of lower potential, which in most cases, is a grounded collector.
- There are many parameters that will influence the morphology of the resultant electrospun fibers, from beaded fibers to fibers with pores on its surface.

- It is also possible to create nanofiber with different morphology by varying the parameters

Process	Technological advances	Can the process be scaled?	Repeatability	Convenient to process?	Control on fiber dimensions
Drawing	Laboratory	X	√	√	X
Template Synthesis	Laboratory	X	√	√	√
Phase Separation	Laboratory	X	√	√	X
Self-Assembly	Laboratory	X	√	X	X
Electro-spinning	Laboratory (with potential for industrial processing	√	√	√	√



2.7.1. Structural design of an electrospinning machine

Apparatus used in electro spinning technique :

- Syringe
- High voltage power supply
- Metallic needle with an orifice at the tip
- Polymer or composite solution
- Collector electrode

2.7.2. Working principle of an electrospinning machine

Electro spinning process can be explained in 5 steps, such as :

a) Charging of the polymer fluid

b) Formation of the cone jet (Taylor cone)

c) Thinning of the jet in the presence of an electric field

d) Instability of the jet

e) Collection of the jet

2.7.3. Electrospinning technique is affected by different parameters.

a) Polymer solution parameters

1) Molecular weight and solution viscosity
2) Surface tension
3) Solution conductivity
4) Dielectric effect of solvent

b) Processing parameters

1) Voltage
2) Feed rate
3) Temperature
4) Effect of collector
5) Diameter of the orifice of needle

(1) Polymer Solution Parameters

The properties of the polymer solution have the most significant influence in the electrospinning process and the resultant fiber morphology.
The surface tension has a part to play in the formation of beads along the fiber length.

The viscosity of the solution and its electrical properties will determine the extent of elongation of the solution.

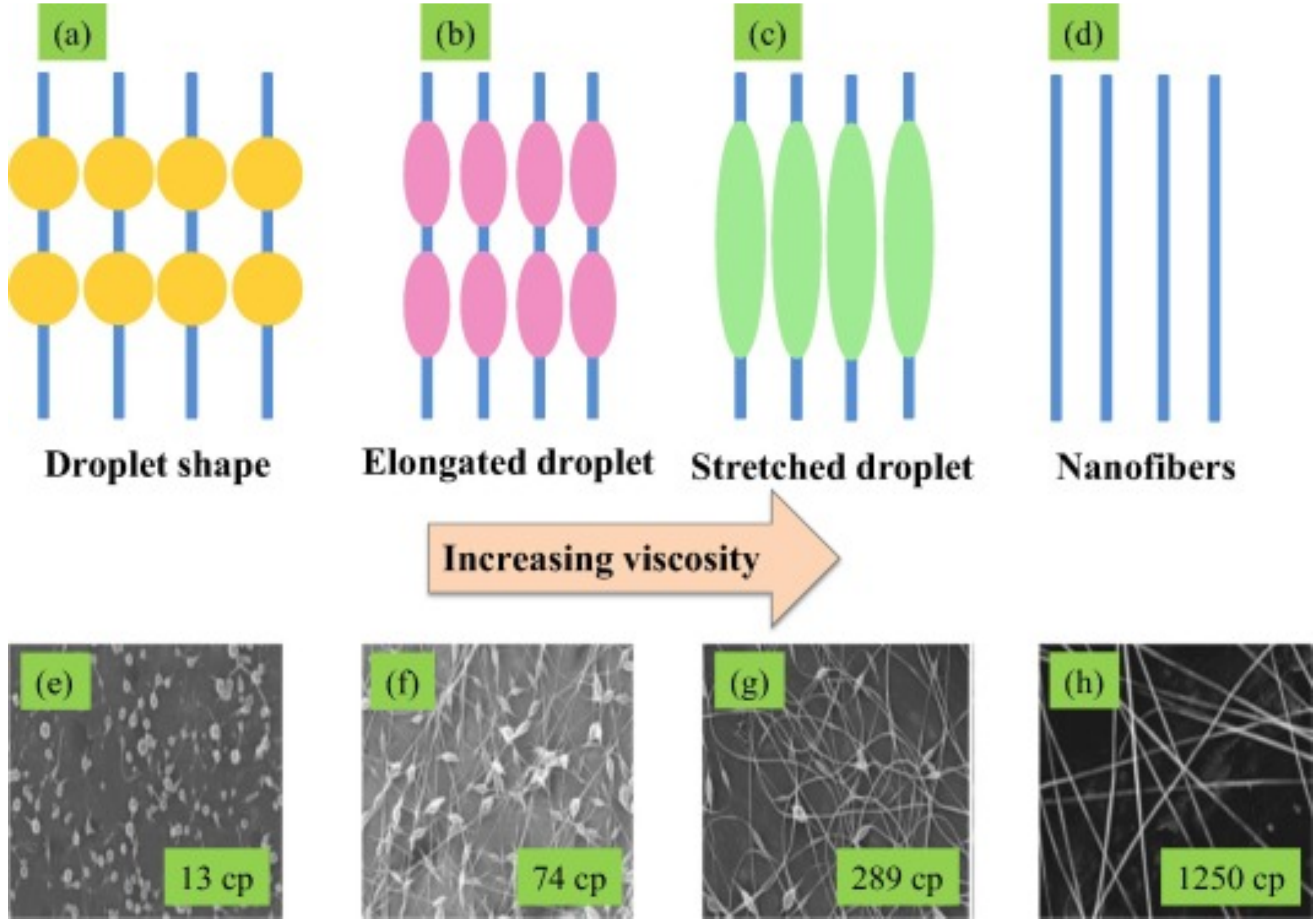
Molecular Weight and Solution Viscosity

Higher the molecular weight of the polymer, increases molecular entanglement in the solution, hence there is increase in viscosity. The electro spun jet eject with high viscosity during it is stretched to collector electrode leading to formation of continuous fiber with higher diameter (Koshki et. al., materials letters 60 (2006), but very high viscosity makes difficult to pump the solution and also lead to the drying of the solution at the needle tip. As very low viscosity lead to bead formation in the resultant electro spun fiber, so the molecular weight and viscosity should be acceptable to form nanofiber.

Increasing the concentration of the polymeric solution will lead to an increase in the viscosity, which then increases the chain entanglement among the polymer chains.

These chain entanglements overcome the surface tension and ultimately result in uniform beadless electrospun nanofibers.

Furthermore, increasing the concentration beyond a critical value (the concentration at which beadless uniform nanofibers are formed) hampers the flow of the solution through the needle tip (the polymer solution dries at the tip of the metallic needle and blocks it), which ultimately results in defective or beaded nanofibers

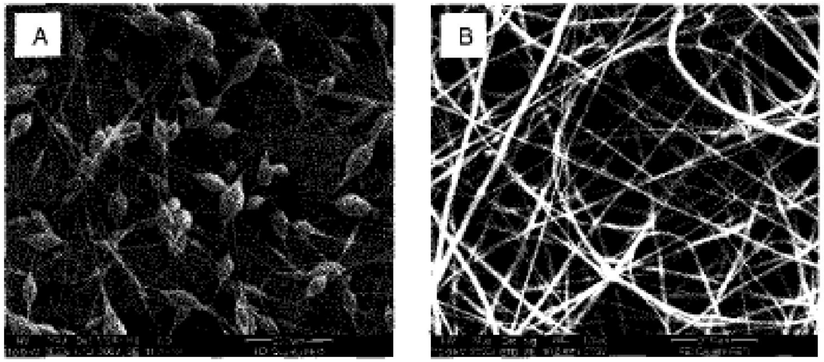

(a)
(b)
(c)
(d)
Droplet shape
Elongated droplet
Stretched droplet
Nanofibers
Increasing viscosity
(e)
13 cp
(f)
74 cp
(g)
289 cp
(h)
1250 cp

The polymer chain entanglements were found to have a significant impact on whether the electrospinning jet breaks up into small droplets or whether resultant electrospun fibers contain beads.
Although a minimum amount of polymer chain entanglements and thus, viscosity is necessary for electrospinning, a viscosity that is too high will make it very difficult to pump the solution through the syringe needle. Moreover, when the viscosity is too high, the solution may dries at the tip of the needle before electrospinning can be initiated.

Many experiments have shown that a minimum viscosity for each polymer solution is required to yield fibers without beads
At a low viscosity, it is common to find beads along the fibers deposited on the collection plate.
At a lower viscosity, the higher amount of solvent molecules and fewer chain entanglements will mean that surface tension has a dominant influence along the electrospinning jet causing beads to form along the fiber.

When the viscosity is increased, the charges on the electrospinning jet will be able to fully stretch the solution with the solvent molecules distributed among the polymer chains.

With increased viscosity, the diameter of the fiber also increases

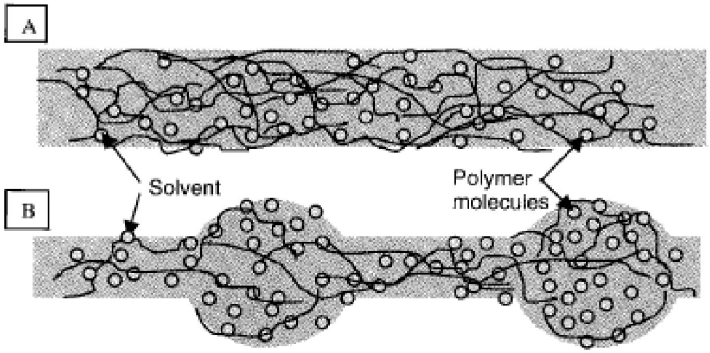


Surface Tension

Lower viscosity leads to decrease in surface tension resulting bead formation along the fiber length because the surface area is decreased, but at higher viscosity effect of surface tension is nullified because of the uniform distribution of the polymer solution over the entangled polymer molecules. So, lower surface tension is required to obtain smooth fiber and lower surface tension can be achieved by adding of surfactants in polymer solution

At higher viscosity there is greater interaction between the solvent and polymer molecules thus when the solution is stretched under the influence of the charges, the solvent molecules will tend to spread over the entangled polymer.

Solvent such as ethanol has a low surface tension thus it can be added to encourage the formation of smooth fibers.



Even when insoluble surfactant is dispersed in a solution fiber morphology is also improved.

Solution Conductivity

Electrospinning involves stretching of the solution caused by repulsion of the charges at its surface. [Repulsion of the charges at the surface of the electrospinning jet causes the solution to stretch and form the nanofibers, and the stretching of the electrospun jet and the bending instability are mainly controlled by the Coulomb force between charges and the force due to the external electric field. Both these forces emerge due to the surface charge on the jet; hence, it can be varied by changing the conductivity of the solution]

The conductivity of the solution can be increased by the addition of ions. most drugs and proteins form ions when dissolved in water.

when a small amount of salt or polyelectrolyte is added to the solution, the increased charges carried by the solution will increase the stretching of the solution. As a result, smooth fibers.

The increased in the stretching of the solution also will tend to yield fibers of smaller diameter. Since the presence of ions increases the conductivity of the solution, the critical voltage for electrospinning to occur is also reduced. Another effect of the increased charges is that it results in a greater bending instability.

As a result, the deposition area of the fibers is increased. This will also favor the formation of finer fibers since the jet path is now increased.

Electrospun fibers from a solution with dissolved NaCl was found to have the smallest diameter while fibers from a solution with dissolved KH2PO4 had the largest diameter and fibers electrospun from solution with NaH2PO4 dissolved had intermediate diameter.

Dielectric Effect of Solvent

Generally, a solution with a greater dielectric property reduces the beads formation and the diameter of the resultant electrospun Fiber.

Solvents such as N,N-Dimethylformamide (DMF) may added to a solution to increase its dielectric property to improve the fiber morphology.

The bending instability of the electrospinning jet also increases with higher dielectric constant.

This may also facilitate the reduction of the fiber diameter due to the increased jet path.

However, if a solvent of a higher dielectric constant is added to a solution to improve the electrospinnability of the solution, the interaction between the mixtures such as the solubility of the polymer will also have an impact on the morphology of the resultant fibers.

(2) Processing Conditions

Voltage

Generally, both high negative or positive voltage of more than 6kV is able to cause the solution drop at the tip of the needle to distort into the shape of a Taylor Cone during jet initiation.

If the applied voltage is higher, the greater amount of charges will cause the jet to accelerate faster and more volume of solution will be drawn from the tip of the needle. This may result in a smaller and less stable Taylor Cone.

In most cases, a higher voltage will lead to greater stretching of the solution due to the greater columbic forces in the jet as well as the stronger electric field. These have the effect of reducing the diameter of the fibers -

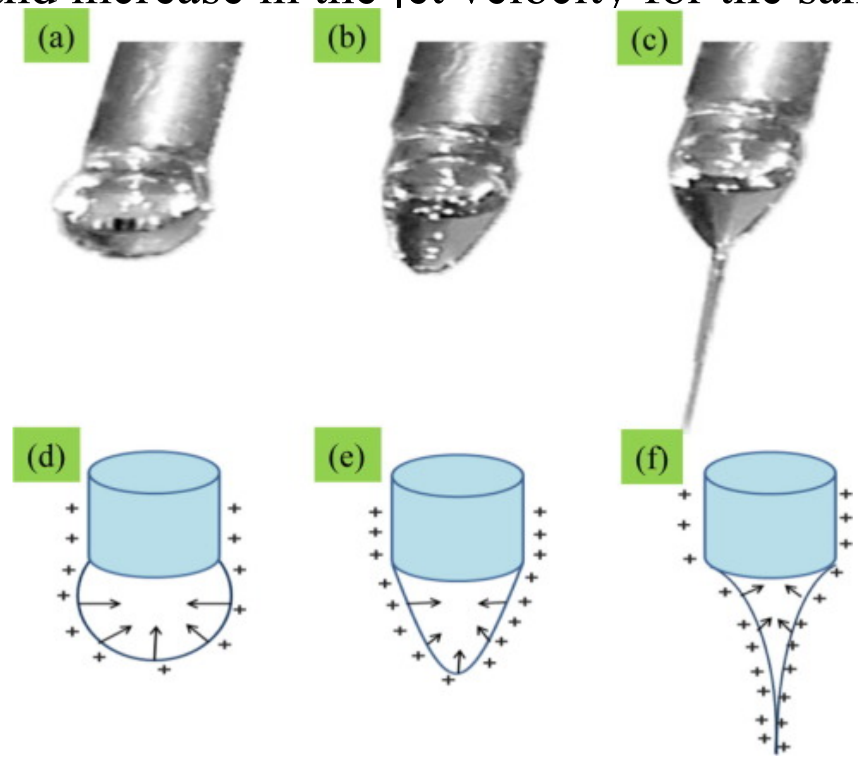
When a solution of lower viscosity is used, a higher voltage may favor the formation of secondary jets during electrospinning. This has the effect of reducing the fiber diameter

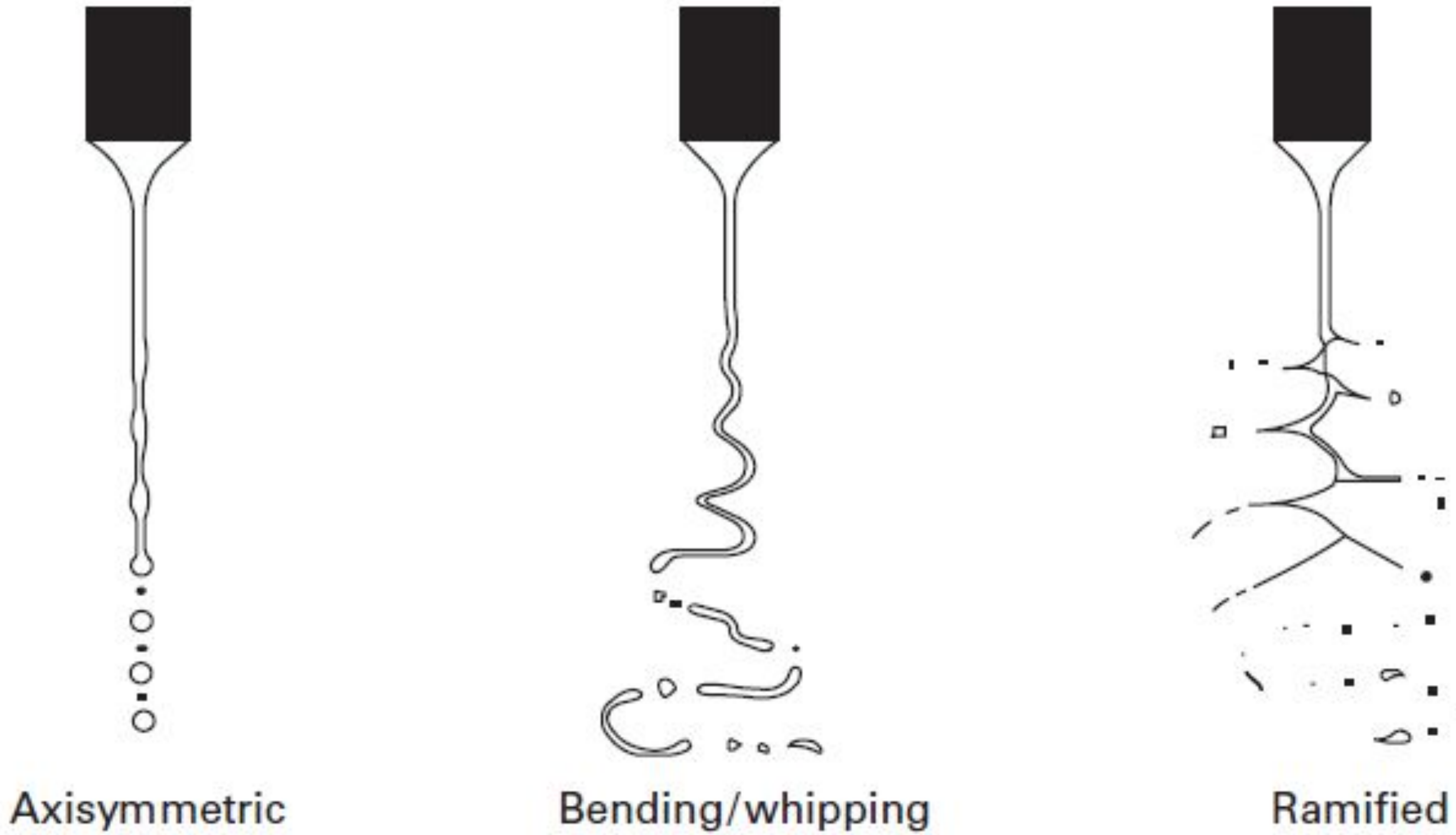
At a higher voltage, it was found that there is a greater tendency for beads formation.
It was also reported that the shape of the beads changes from spindle-like to spherical-like with increasing voltage

The formation of smaller-diameter nanofibers with an increase in the applied voltage is attributed to the stretching of the polymer solution in correlation with the charge repulsion within the polymer jet

An increase in the applied voltage beyond the critical value will result in the formation of beads or beaded nanofibers.

The increases in the diameter and formation of beads or beaded nanofibers with an increase in the applied voltage are attributed to the decrease in the size of the Taylor cone and increase in the jet velocity for the same flow rate.





1.3 Principal jet break-up modes (adapted from Ref. 11).

The effect of high voltage is not only on the physical appearance of the fiber, it also affects the crystallinity of the polymer fiber.

The electrostatic field may cause the polymer molecules to be more ordered during electrospinning thus induces a greater crystallinity in the fiber.

Feedrate

For a given voltage, there is a corresponding feedrate if a stable Taylor cone is to be maintained.

When the feedrate is increased,there is a corresponding increase in the fiber diameter or beads size.

However, there is a limit to the increase in the diameter of the fiber due to higher feedrate.

Due to the greater volume of solution drawn from the needle tip, the jet will takes a longer time to dry. As a result, the solvents in the deposited fibers may not have enough time to evaporate given the same flight time.

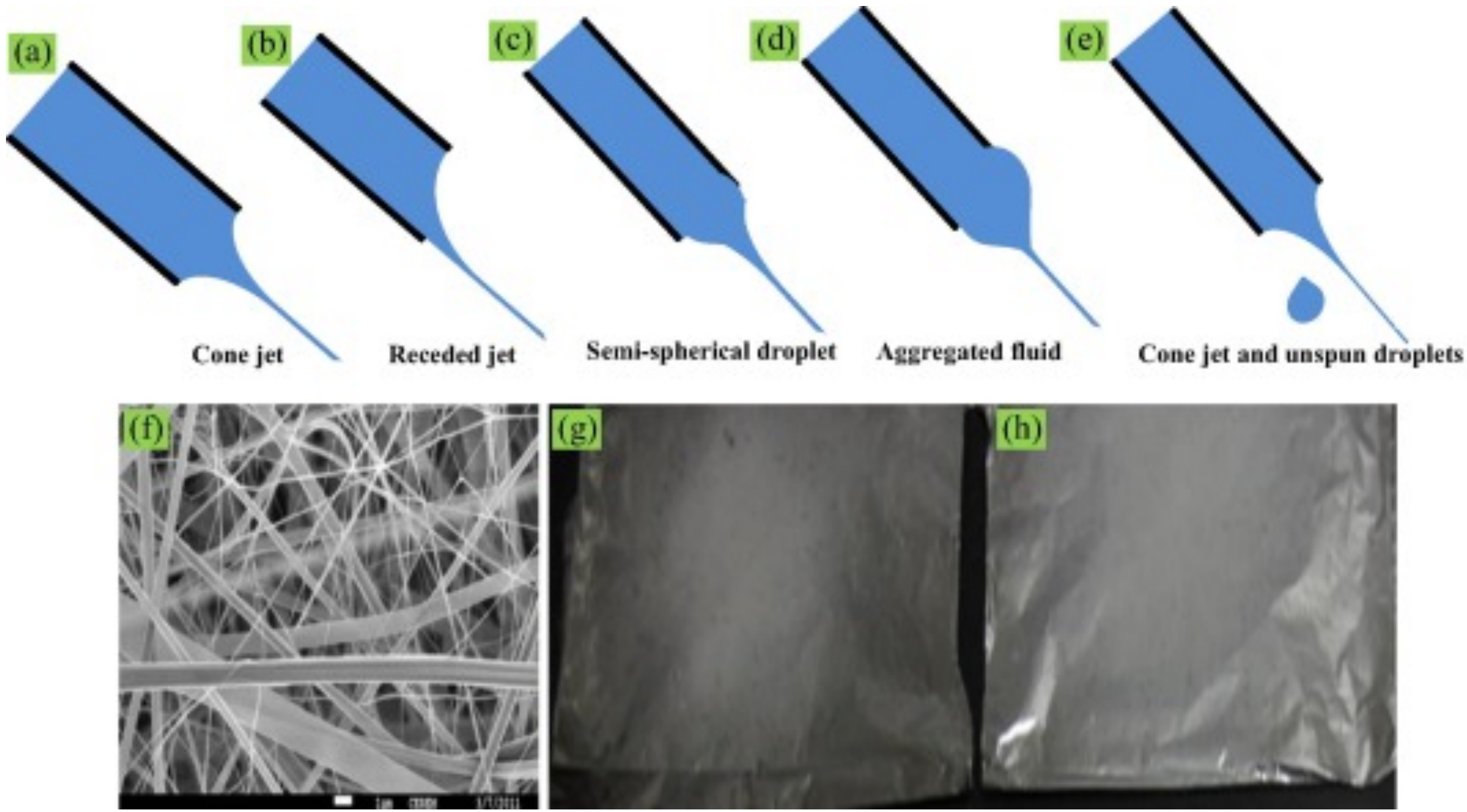
The residual solvents may cause the fibers to fuse together where they make contact forming webs.

A lower feedrate is more desirable as the solvent will have more time for evaporation.

The flow of the polymeric solution through the metallic needle tip determines the morphology of the electrospun nanofibers.

Uniform beadless electrospun nanofibers could be prepared *via* a critical flow rate for a polymeric solution. This critical value varies with the polymer system. Increasing the flow rate above the critical value could lead to the formation of beads.

Because increase and decrease in the flow rate affect the nanofiber formation and diameter, a minimum flow rate is preferred to maintain a balance between the leaving polymeric solution and replacement of that solution with a new one during jet formation


(a)
(b)
(c)
(d)
(e)
Cone jet
Receded jet
Semi-spherical droplet
Aggregated fluid
Cone jet and unspun droplets
(f)
(g)
(h)

Temperature

The temperature of the solution has both the effect of increasing its evaporation rate and reducing the viscosity of the polymer solution.

When polyurethane is electrospun at a higher temperature, the fibers produced have a more uniform diameter.

This may be due to the lower viscosity of the solution and greater solubility of the polymer in the solvent which allows more even stretching of the solution.

With a lower viscosity, the Columbic forces are able to exert a greater stretching force on the solution thus resulting in fibers of smaller diameter.

Increased polymer molecules mobility due to increased temperature also allows the Columbic force to stretch the solution further.

However, in cases where biological substances such as enzymes and proteins are added to the solution for electrospinning, the use of high temperature may cause the substance to lose its functionality.

Effect of Collector

There must be an electric field between the source and the collector for electrospinning to initiate.

In most electrospinning setup, the collector plate is made out of conductive material such as aluminum foil which is electrically grounded so that there is a stable potential difference between the source and the collector.

In the case when a nonconducting material is used as a collector, charges on the electrospinning jet will quickly accumulates on the collector which will result in fewer fibers deposited.

Fibers that are collected on the non-conducting material usually have a lower packing density compared to those collected on a conducting surface.

This is caused by the repulsive forces of the accumulated charges on the collector as more fibers are deposited.
For a conducting collector, charges on the fibers are dissipated thus allowing more fibers to be attracted to the collector. The fibers are able to pack closely together.

Experiments with porous collector such as paper and metal mesh had shown that the fiber mesh collected had a lower packing density than smooth surfaces such as metal foils.

Diameter of Pipette Orifice / Needle

The internal diameter of the needle or the pipette orifice has a certain effect on the electrospinning process.

A smaller internal diameter was found to reduce the clogging as well as the amount of beads on the electrospun fibers.

Decrease in the internal diameter of the orifice was also found to cause a reduction in the diameter of the electrospun fibers.

When the size of the droplet at the tip of the orifice is decreased, such as in the case of a smaller internal diameter of the orifice, the surface tension of the droplet increases.

For the same voltage supplied, a greater columbic force is required to cause jet initiation.

As a result, the acceleration of the jet decreases and this allows more time for the solution to be stretched and elongated before it is collected.

However, if the diameter of the orifice is too small, it may not be possible to extrude a droplet of solution at the tip of the orifice

Distance between Tip and Collector

In several cases, the flight time as well as the electric field strength will affect the electrospinning process and the resultant fibers.

Varying the distance between the tip and the collector will have a direct influence in both the flight time and the electric field strength.

For independent fibers to form, the electrospinning jet must be allowed time for most of the solvents to be evaporated.

When the distance between the tip and the collector is reduced, the jet will have a shorter distance to travel before it reaches the collector plate. Moreover, the electric field strength will also increase at the same time and this will increase the acceleration of the jet to the collector.

As a result, there may not have enough time for the solvents to evaporate when it hits the collector.

When the distance is too low, excess solvent may cause the fibers to merge where they contact to form junctions resulting in inter and intra layer bonding. This interconnected fiber mesh may provide additional strength to the resultant scaffold.

Applications of nanofibers in tissue engineering

scaffolding is a medical process used to regrow tissue and bone, including limbs and organs. The **nano-scaffold** is a three-dimensional structure composed of polymer fibers very small that are scaled from a Nanometer (10^{-9} m) scale.

In the past decade, nanofibrous systems have been developed and explored as potential scaffolds for tissue engineering.

By virtue of their high surface area and porosity, they have the potential to provide enhanced cell adhesion

By virtue of the similarity of their 3D architecture to natural (ECM) extracellular matrix, they provide an excellent micro/nano environment for cells to grow and perform their regular functions.

Therefore, nanofibrous systems have been strongly pursued as scaffolds for tissue engineering applications.

It is well known that biological tissues consist of well-organized hierarchical fibrous structures ranging from nanometer to micrometer scale.

Fabrication of nanofibrous scaffolds

Tissue engineering scaffolds should have the following characteristics:

• porosity for cell migration;

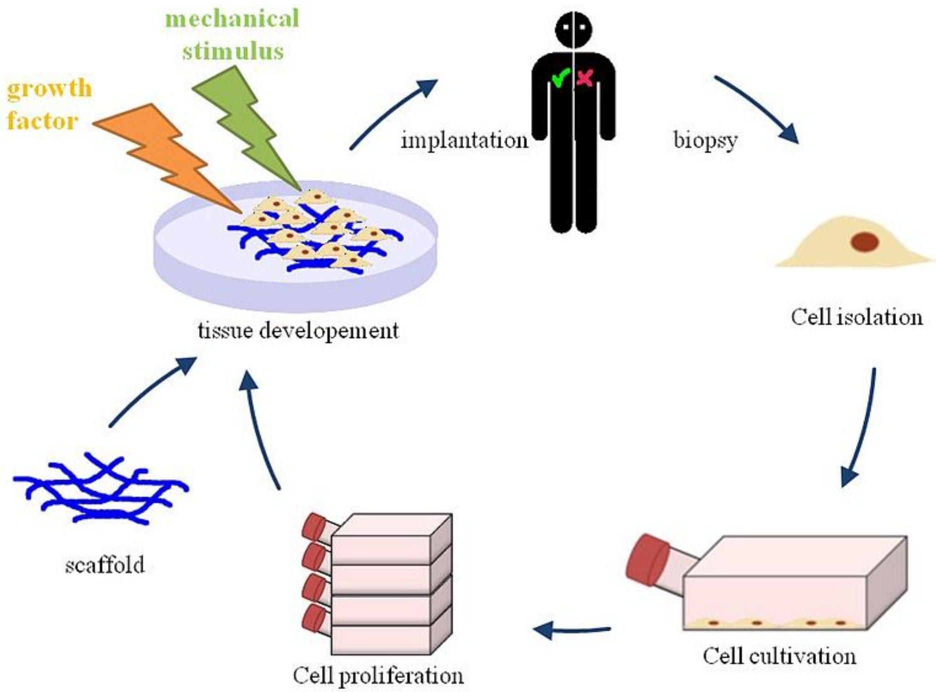
• balance between surface hydrophilicity and hydrophobicity for cell attachment;

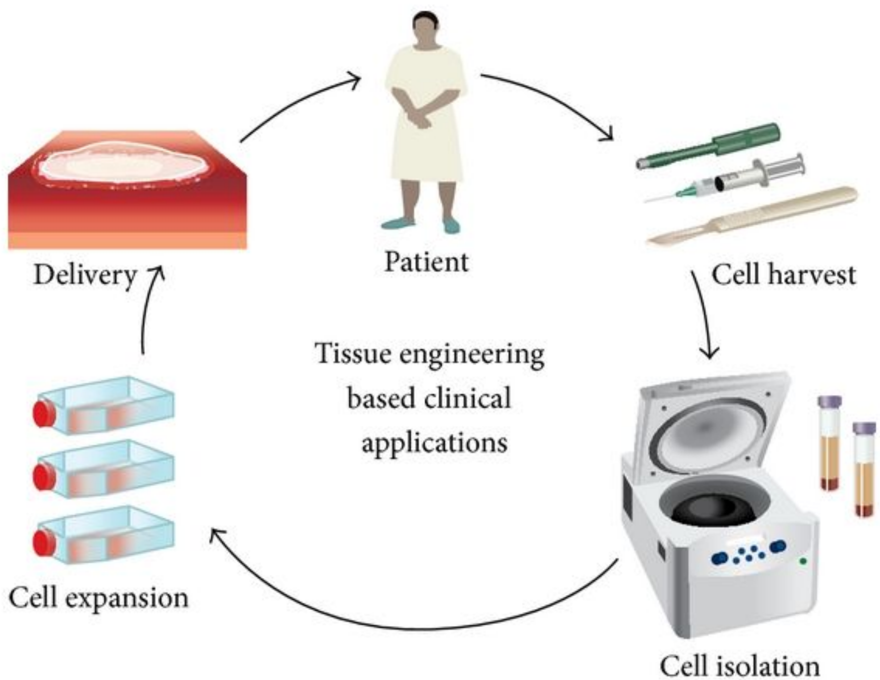
• mechanical properties comparable to natural tissue to withstand natural loading conditions;

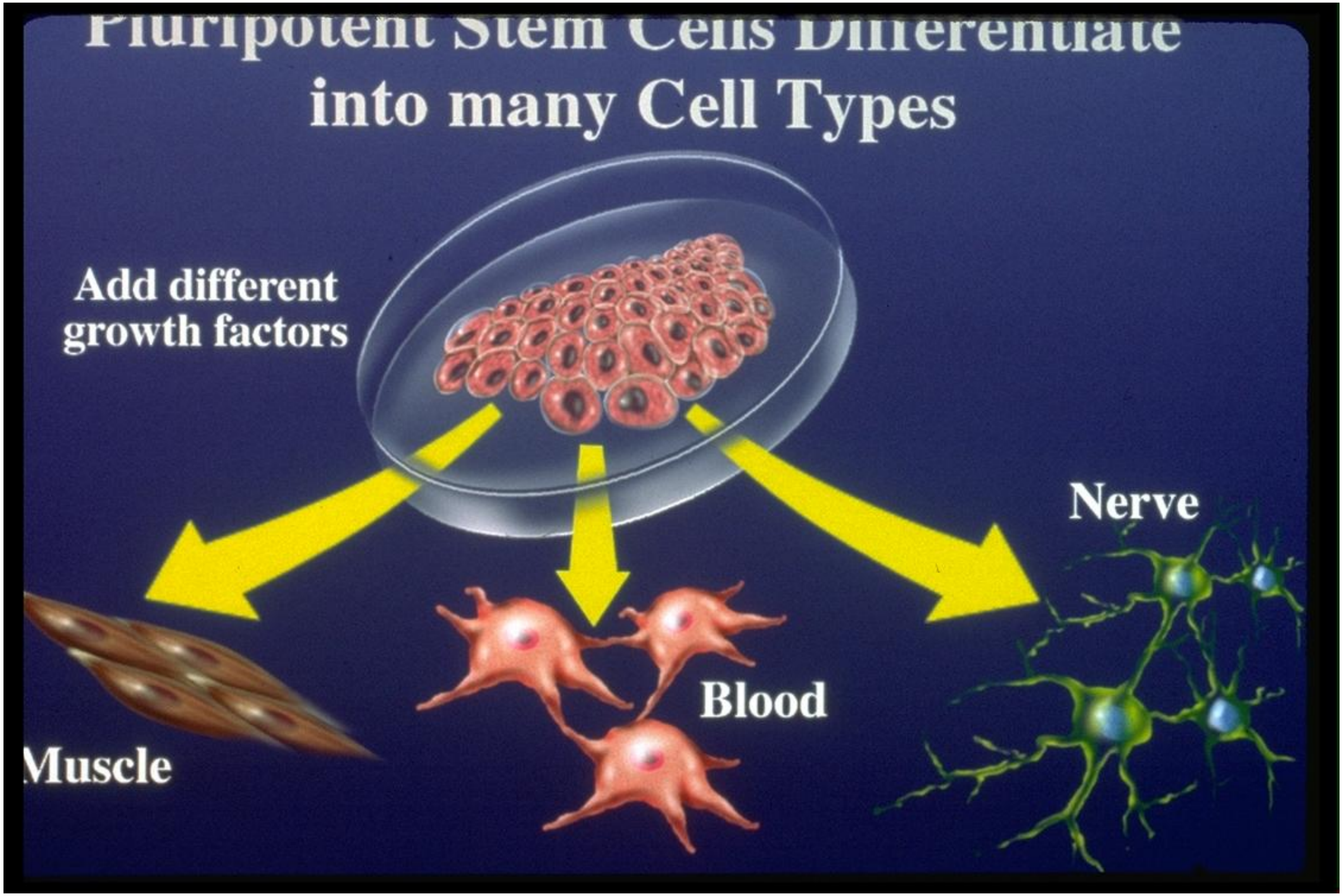
• degradation capability so that it gets completely reabsorbed after implantation;

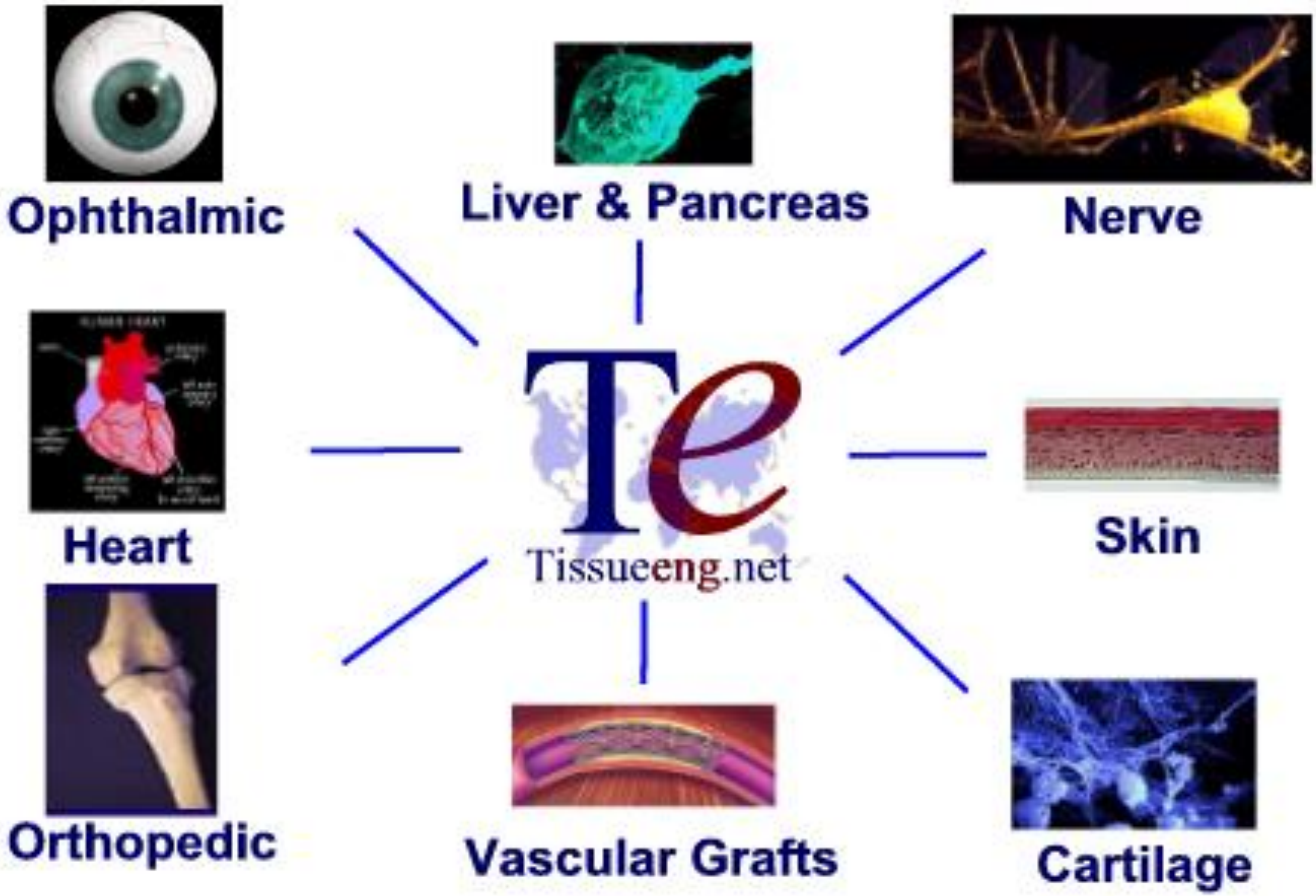
• nontoxic byproducts;

• 3D matrix.


mechanical stimulus
growth factor
implantation
biopsy
tissue developement
Cell isolation
scaffold
Cell proliferation
Cell cultivation


Patient
Delivery
Cell harvest
Tissue engineering based clinical applications
Cell expansion
Cell isolation


Pluripotent Stem Cells Differentiate
into many Cell Types
Add different
growth factors
Nerve
Blood
Muscle


Ophthalmic
Liver & Pancreas
Nerve
Heart
Te
Tissueeng.net
Skin
Orthopedic
Vascular Grafts
Cartilage

Synthetic Nanofiber Trachea after Fabrication at the Nanofiber Solutions Facility in Columbus,, and then after Being Perfused with the Patients' Stem Cells Immediately before Implantation at the Karolinska Institute

Polymer fibers

Scientists around the globe have used various biocompatible and biodegradable synthetic polymeric biomaterials including **polylactic (PLA) and glycolic acids(PGA), and their copolymers for scaffold fabrication.**

Various non-degradable materials such as polyester, polypropylene, polytetrafluoroethylene, polyethylene and polycarbonates are used as well.

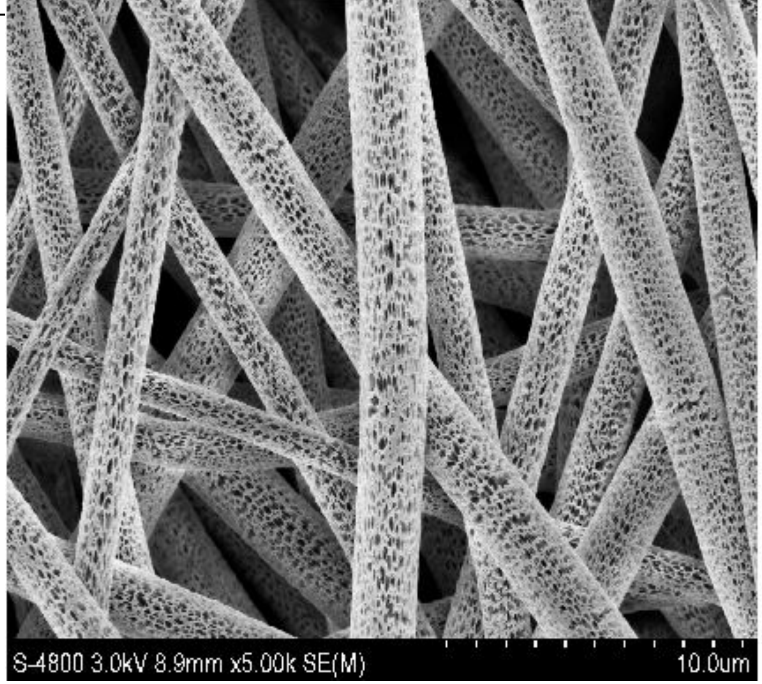
The main advantages of synthetic polymers are they are available in bulk and their properties are tailorable. However they lack cell recognition signals and sometimes their degraded products may be toxic.

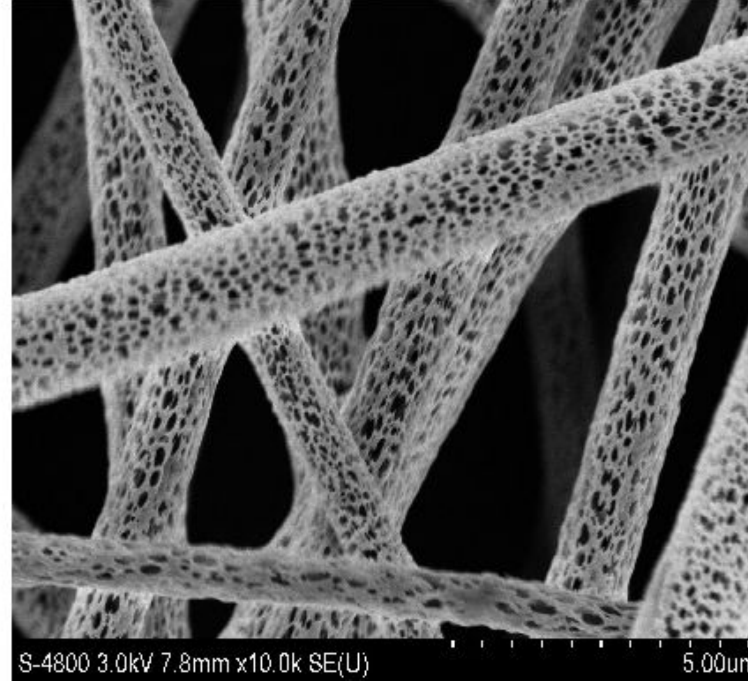
PLA, PGA and PLAGA are the most abundantly used polymers for scaffold fabrication.

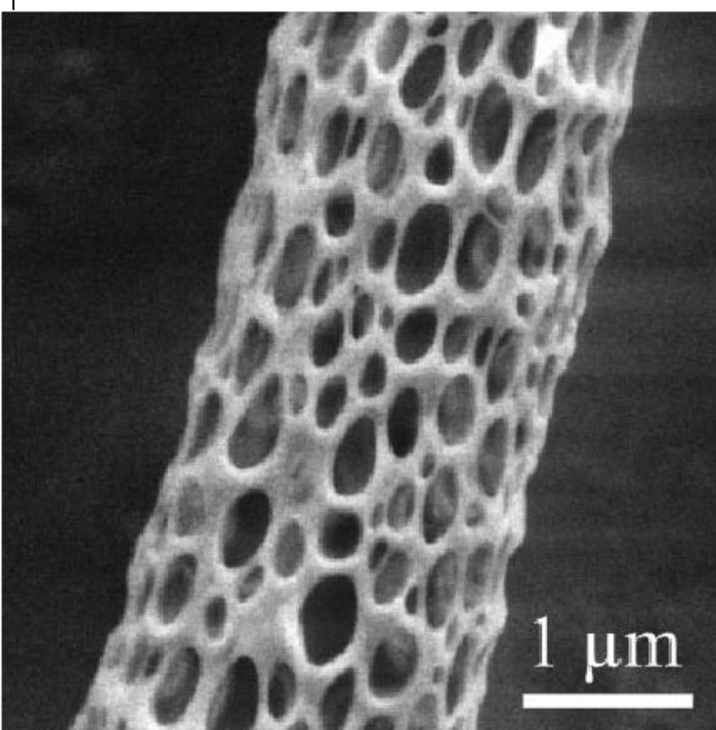
These are US Food and Drug Administration (FDA) approved polymers and their mechanical and degradable properties can be tailored by varying the ratio of PLA to PGA.

Continuous, uniform and nanoscale fibers of PLA to PGA were produced by the electrospinning process.

These electrospun nanofibrous scaffolds have a large surface area to volume ratio, high porosity and a variety of pore size distribution, giving all the important features necessary for ideal tissue engineering scaffolds.

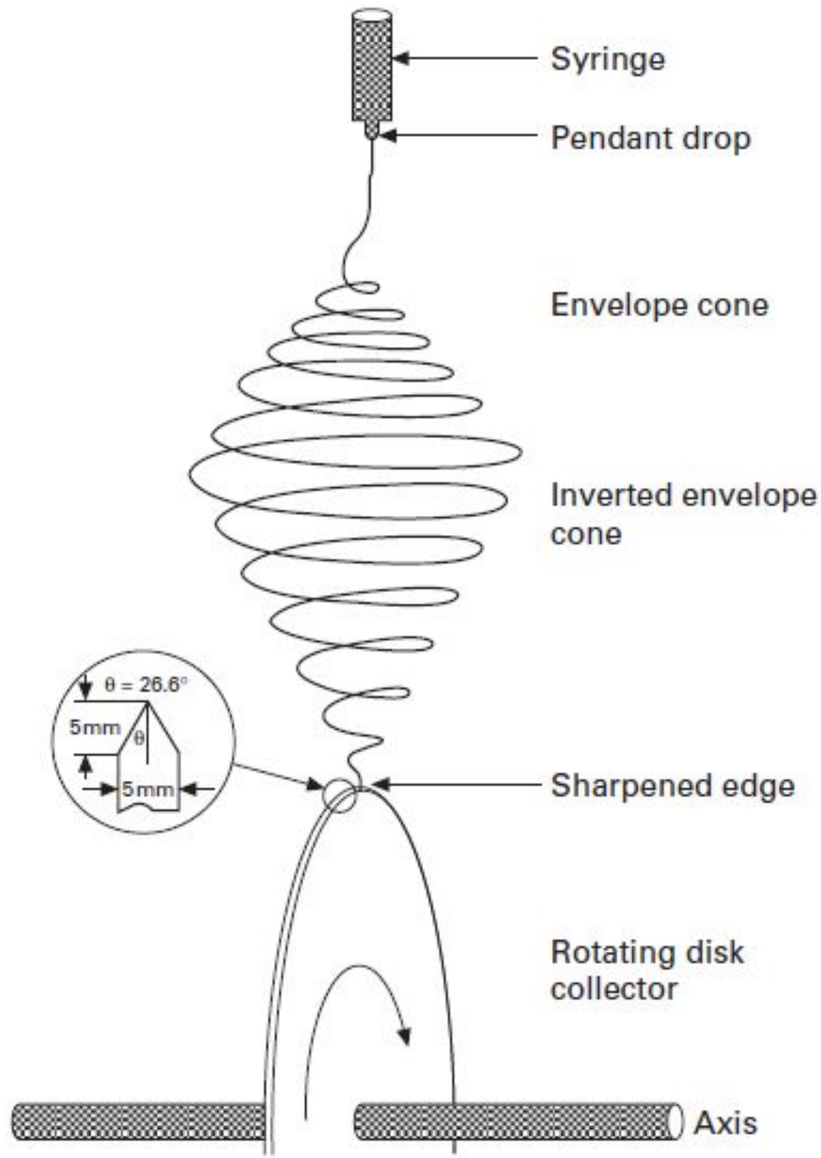




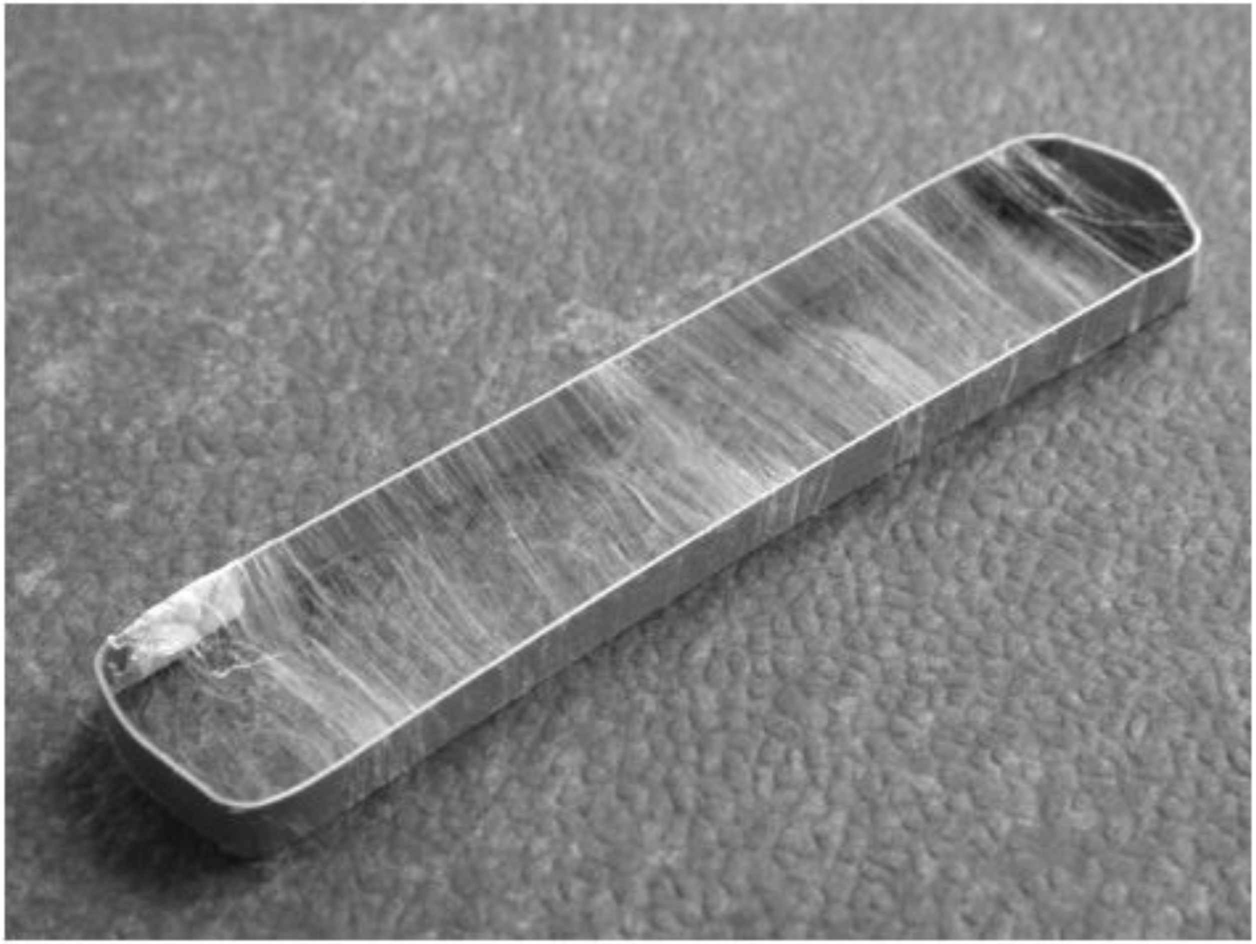


POROUS
NANOFIBERS

CONTROLLING THE MORPHOLOGY OF NANOFIBER



Syringe
Pendant drop
Envelope cone
Inverted envelope cone
θ = 26.6°
5mm
θ
5mm
Sharpened edge
Rotating disk collector
Axis



3.2 Aligned fibers obtained through the gap alignment effect. Reprinted from reference 14 and kindly supplied by R. Dersch. Copyright (2003), with permission from John Wiley & Sons Inc

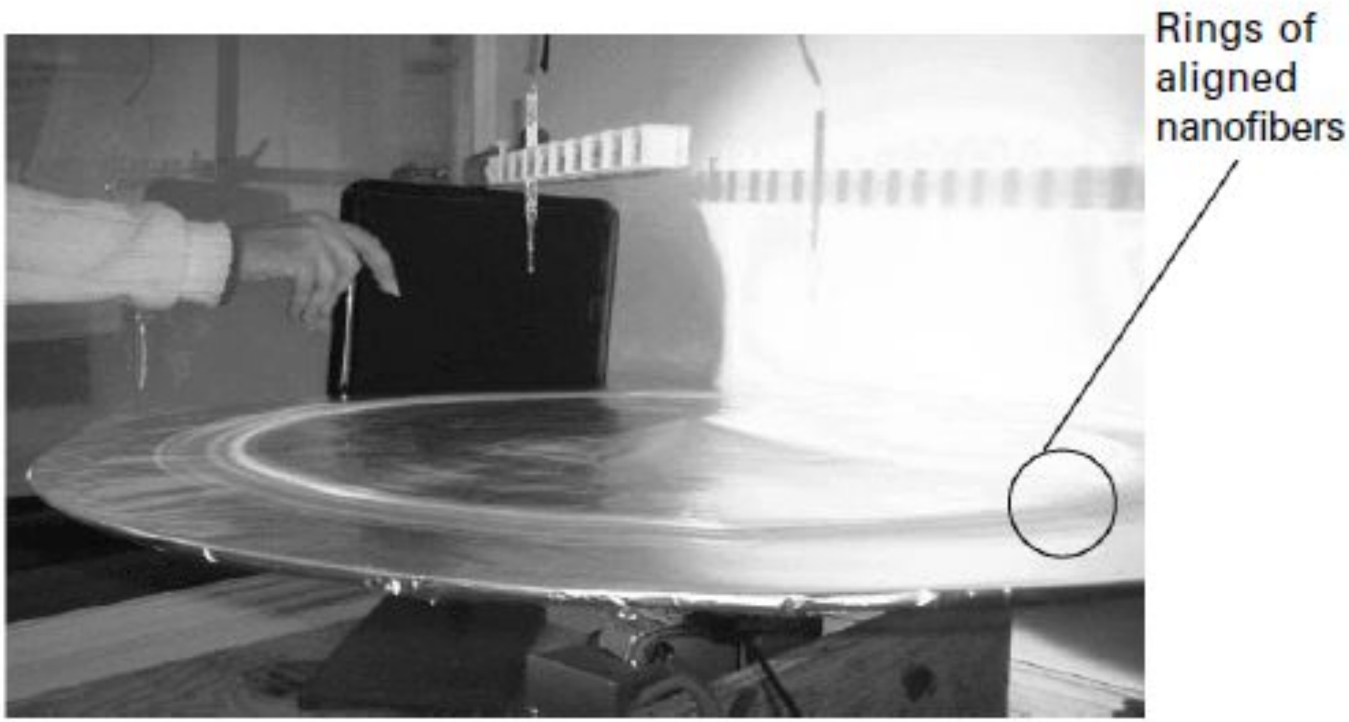
The gap alignment effect – uniaxially aligned arrays of electrospun fibers can be obtained through the gap alignment effect, which occurs when charged electrospun fibers are deposited onto a collector that consists of two electrically conductive substrates, separated by an insulating gap.

This electrostatic effect (see Fig. 3.2) has been observed by various groups.

Briefly, the lowest energy configuration for an array of highly charged fibers between two conductive substrates, separated by an insulating gap, is obtained when fibers align parallel to each other.

Both spinning onto a rapidly rotating collector and the gap alignment effect have been used to obtain short yarns for

Rotating collector method



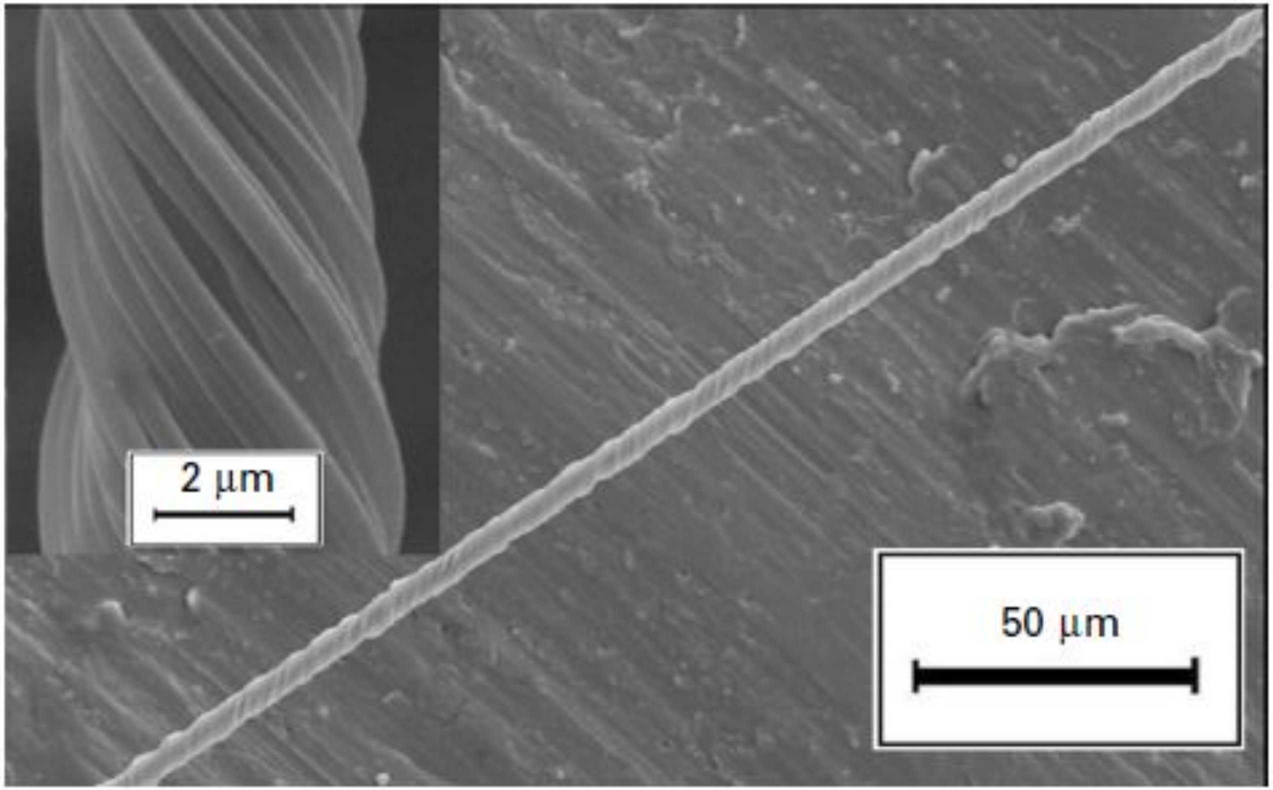
In work performed at Drexel University19 poly(ethylene oxide) (PEO) fibers were spun onto a rapidly rotating disk , where the shearing force of the rotating disk led to aligned fibrous assemblies with good orientation.

These oriented fibers could then be collected and manually twisted into a yarn

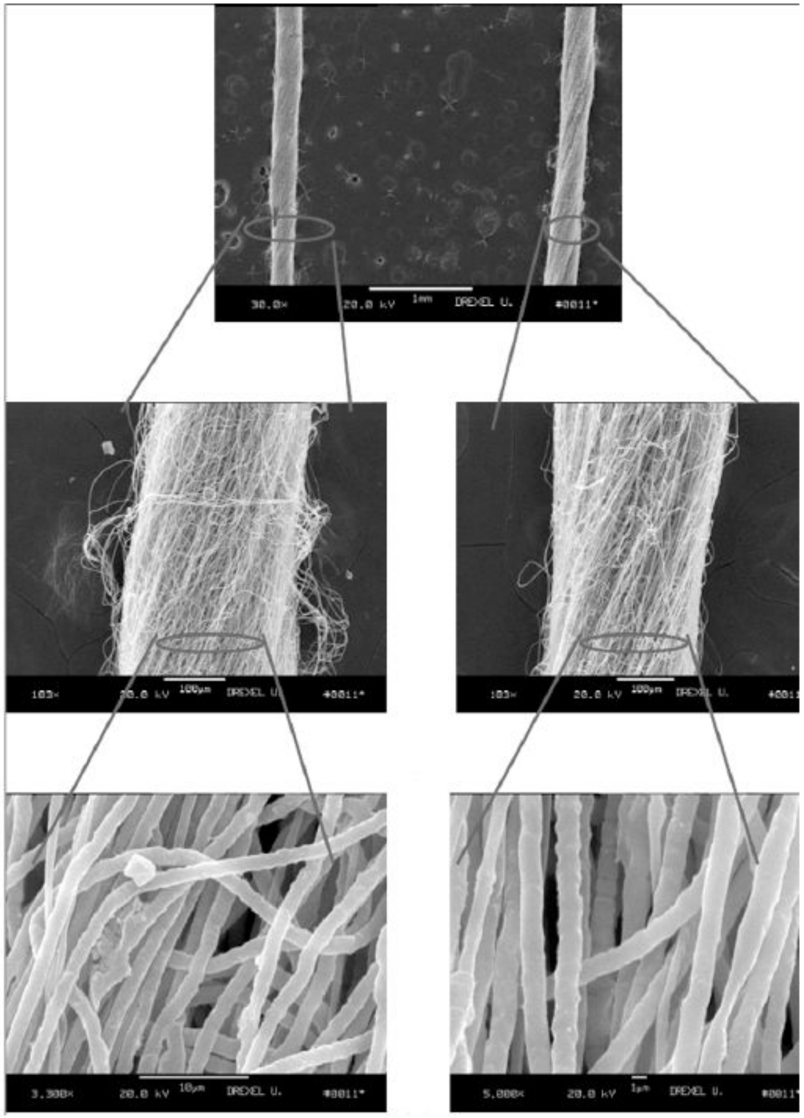
Fennessey and Farris20 collected tows of aligned polyacrylonitrile (PAN) fibers using a rotating drum set-up.

The tows, measuring *ca. 32 cm × 2 cm,* were then linked together and twisted using a Roberta-type electric twister. Twisted yarns of PAN nanofibers with twist angles of between 1.1° and
16.8° were prepared.

The stress–strain behaviour of the yarns was examined and the modulus, ultimate strength and elongation at the ultimate strength were measured as a function of twist angle

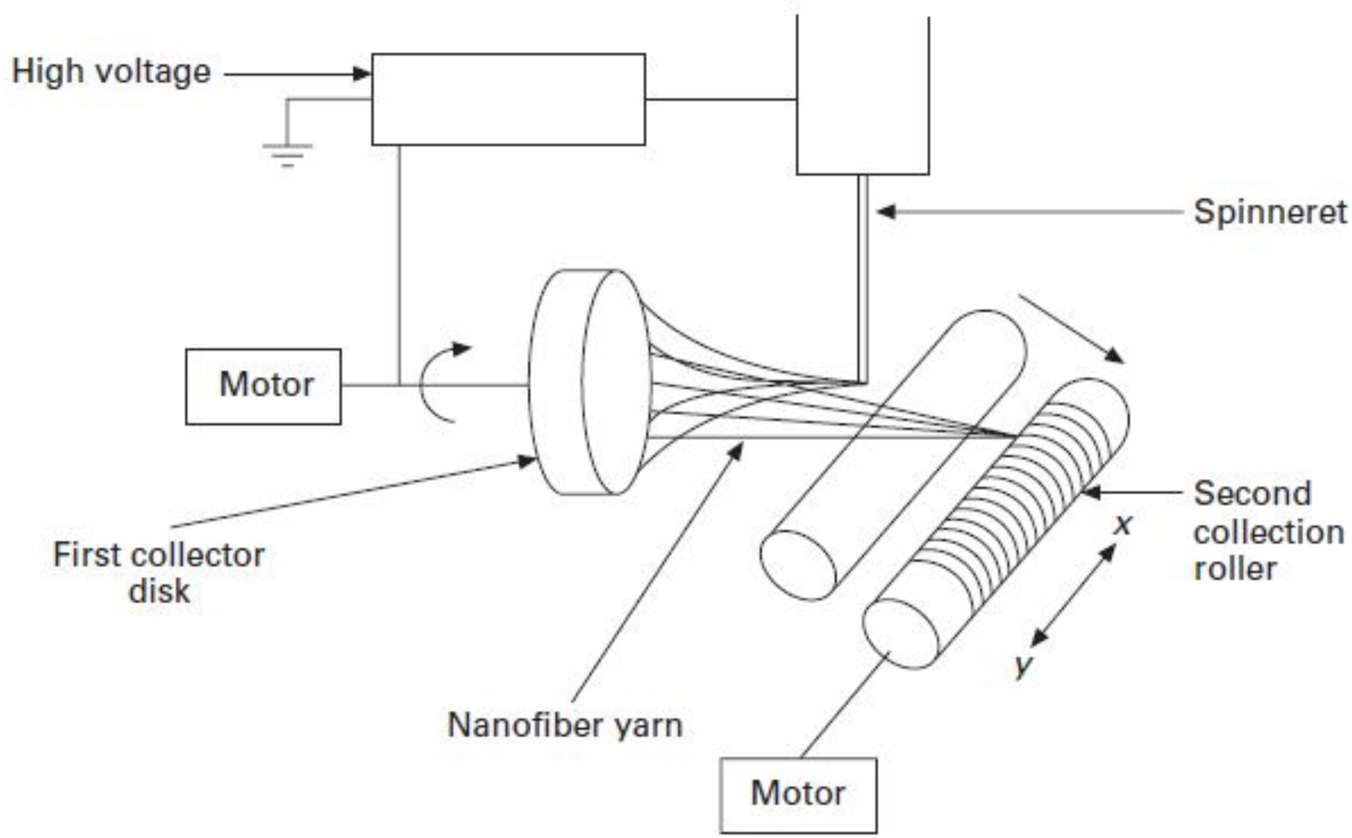


3.6 Twisted poly(ε-caprolactone) yarn. Reprinted from reference 24



3.4 Twisted yarns obtained from tows spun on a rotating disk collector. Reprinted with permission from reference 19 with kind permission from the author.

Multi-collector yarn



In this patented process from the Korea Research Institute of Chemical Technology, continuous slivers or twisted yarns of different polymers, but especially of polyamide–polyimide copolymers, are claimed to be obtained by electrospinning first onto one stationary or rotating plate or conductive mesh collector, where the charges on the fibers are neutralized, and then continuously collecting the fibers from the first onto a second rotating collector.

A diagram depicting the process is given in . The underlying principle of this process closely resembles the rotating dual-collector yarn process

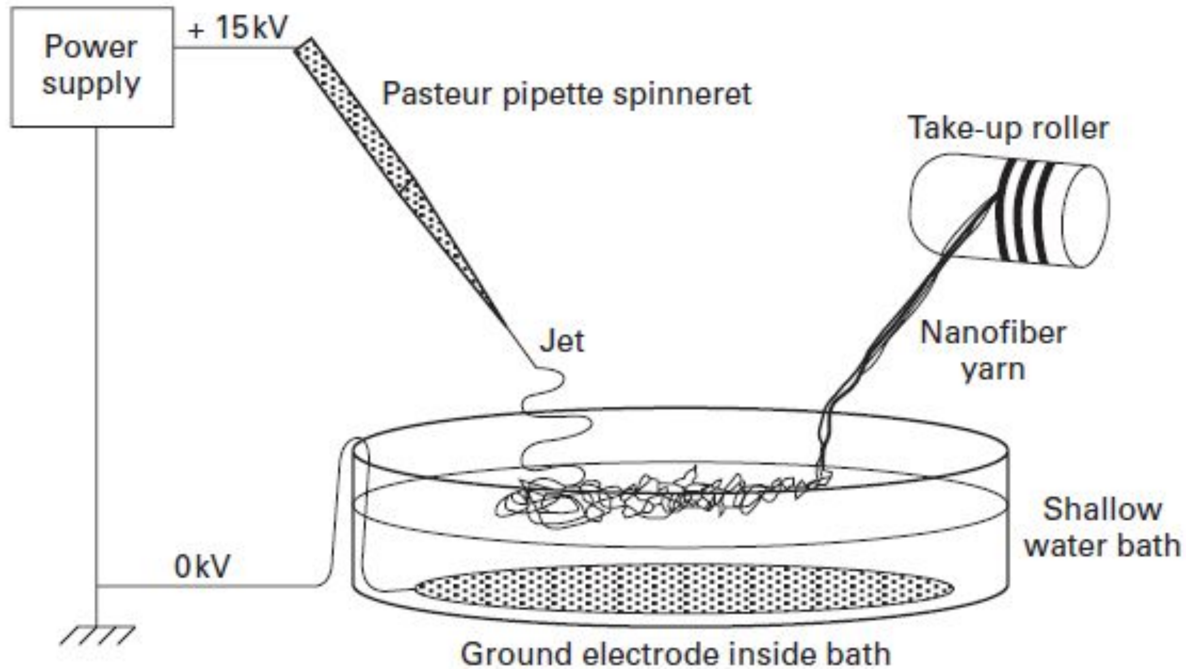
Self-assembled yarn

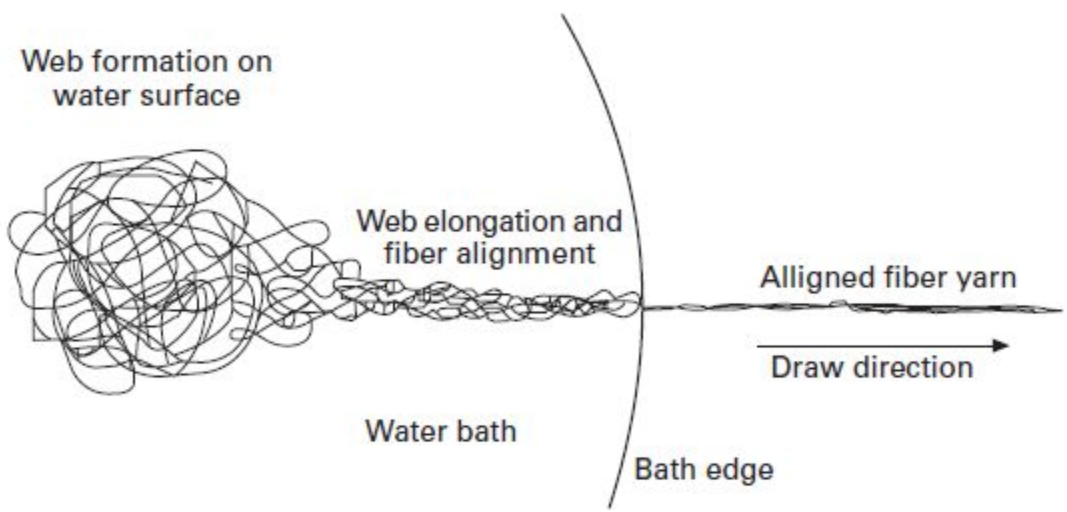
3.8 Self-assembled yarn formation. Reprinted with permission from

The self-assembled yarn process was developed by Ko *et al. at Drexel* University.

When a solution of pure PAN, or a PAN-containing polymer blend, was electrospun onto a solid conductive collector under appropriate conditions, the fibers did not deposit on the collector in the form of a flat nonwoven web as is usually observed. Instead, initial fibers deposited on a relatively small area of the collector and then subsequent fibers started accumulating on top of them and then on top of each other, forming a selfassembled yarn structure that rapidly grew upwards from the collector towards the spinneret.

Spin-bath collector yarn





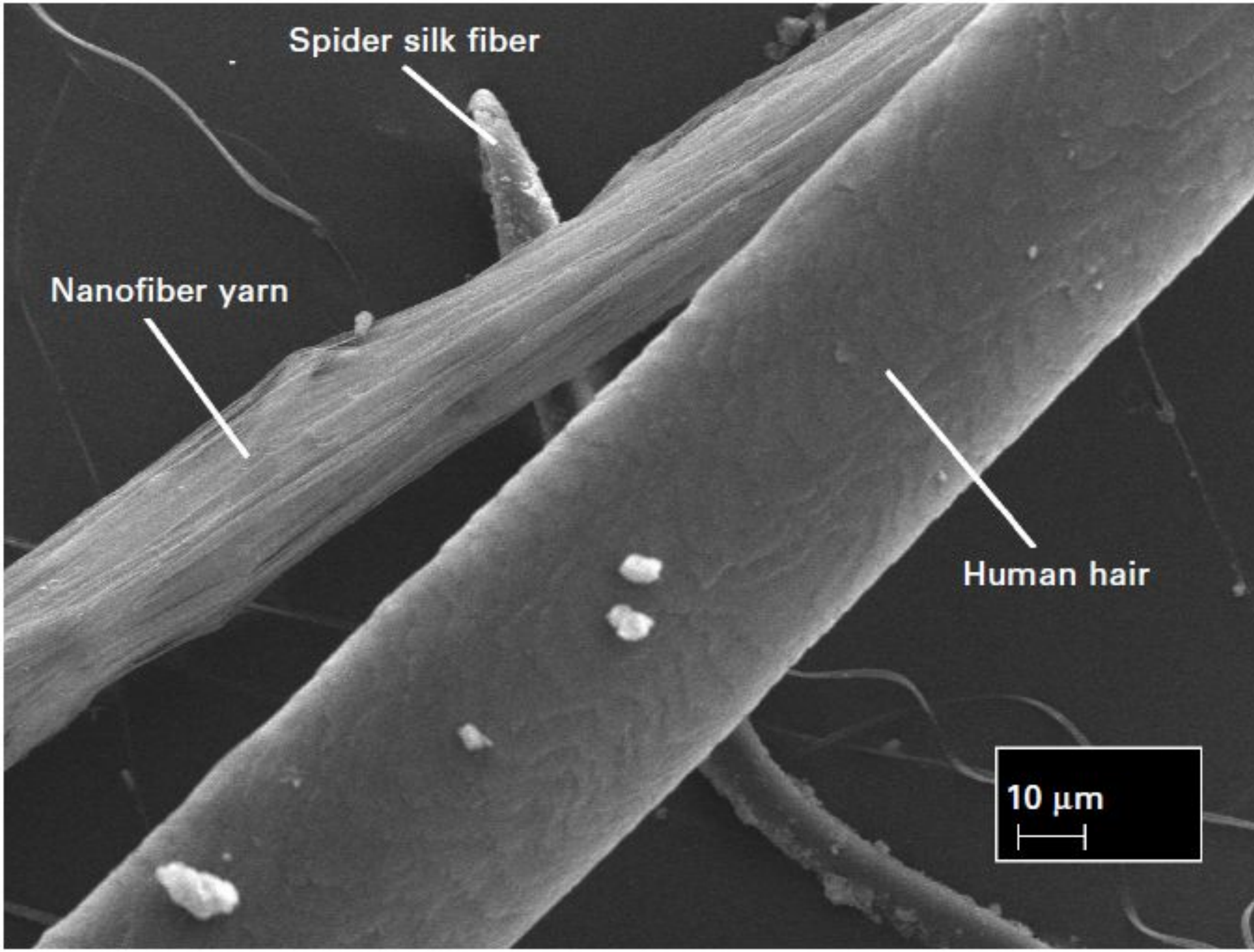
continuous uniaxial fiber bundle yarns are obtained by electrospinning onto the surface of a liquid reservoir counter-electrode. The web of electrospun fibers, which forms on the surface of the spin-bath, is drawn at low linear velocity (*ca. 0.05 m/s) over the liquid surface and onto* a take-up roller. A diagrammatic representation of the electrospinning set-up is given in

All the yarns obtained using this method exhibit very high degrees of fiber alignment (see Fig. 3.10) and bent fiber loops are observed in all the yarns

The process of yarn formation is illustrated in . It can be described in **three phases**. In the first phase, a flat web of randomly looped fibers forms on the surface of the liquid. In the second phase, when the fibers are drawn over or through the liquid, the web is elongated and alignment of the fibers takes place in the drawing direction.

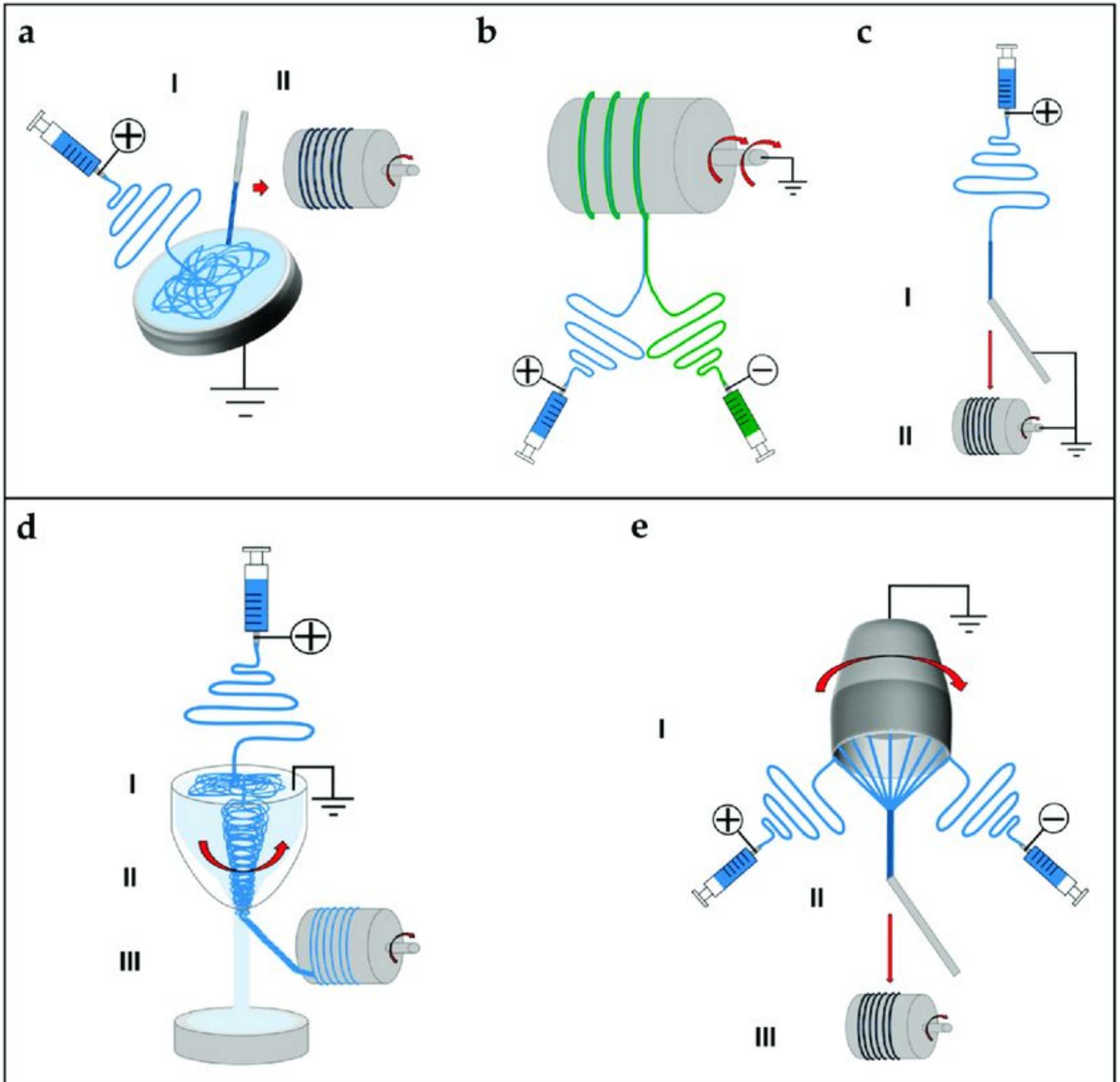
The third phase consists of drawing the web off the liquid and into air. The surface tension of the remaining liquid on the web pulls the fibers together into a three-dimensional, round yarn structure.

The average yarn obtained in a single-spinneret electrospinning set-up contains approximately 3720 fibers per cross-section and approximately 180m of yarn

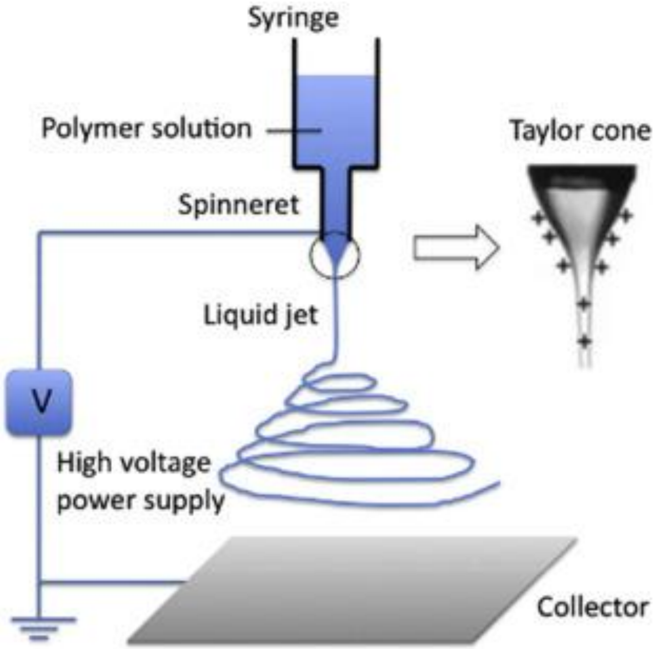


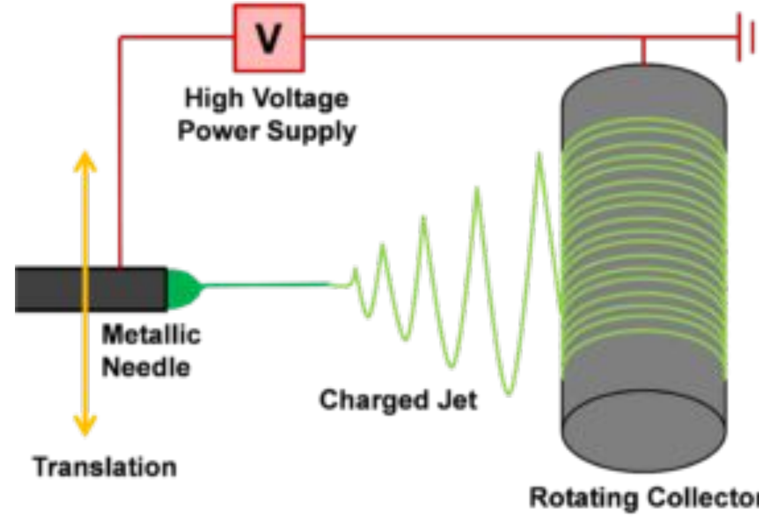
3.12 Relative sizes of nanofiber yarn, spider silk fiber and human hair.

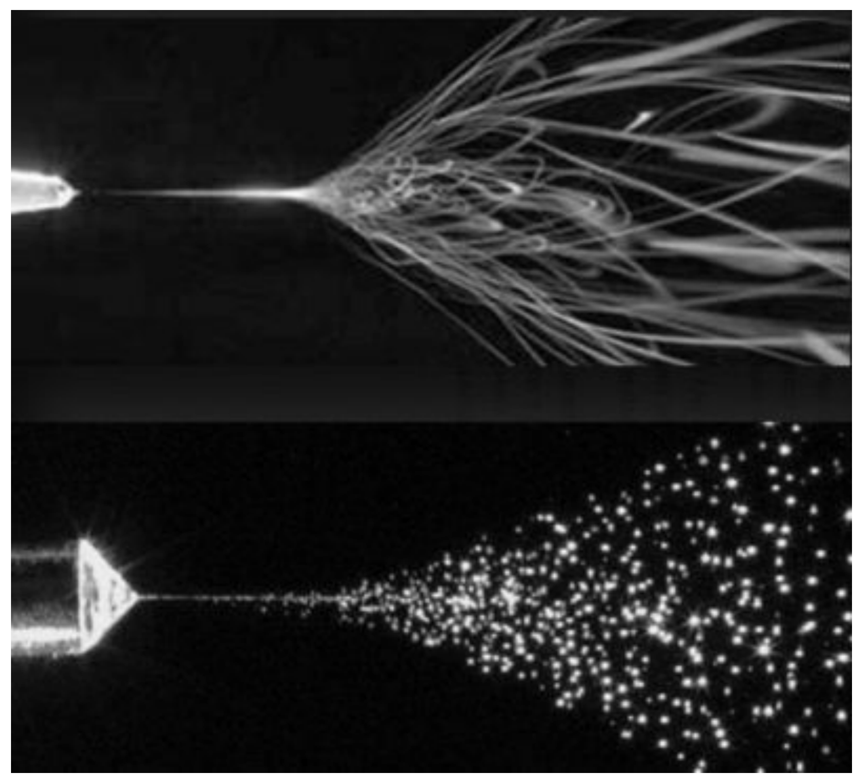
- Electrospinning is a unique method of producing continuous polymer fibres
- Studies on understanding the electrospinning process, its operating parameters and material properties have been extensive
- Improved electrospinning methods, new fibre structures and potential applications are continually emerging
- The electrospun nanofibres usually have a regular threadlike structure and some fibres can form a ribbon-like fibrous morphology. The fibre diameter varies in range from 5 nm to 10μm



a
I
II
b
c
I
II
d
I
II
III
e
I
II
III

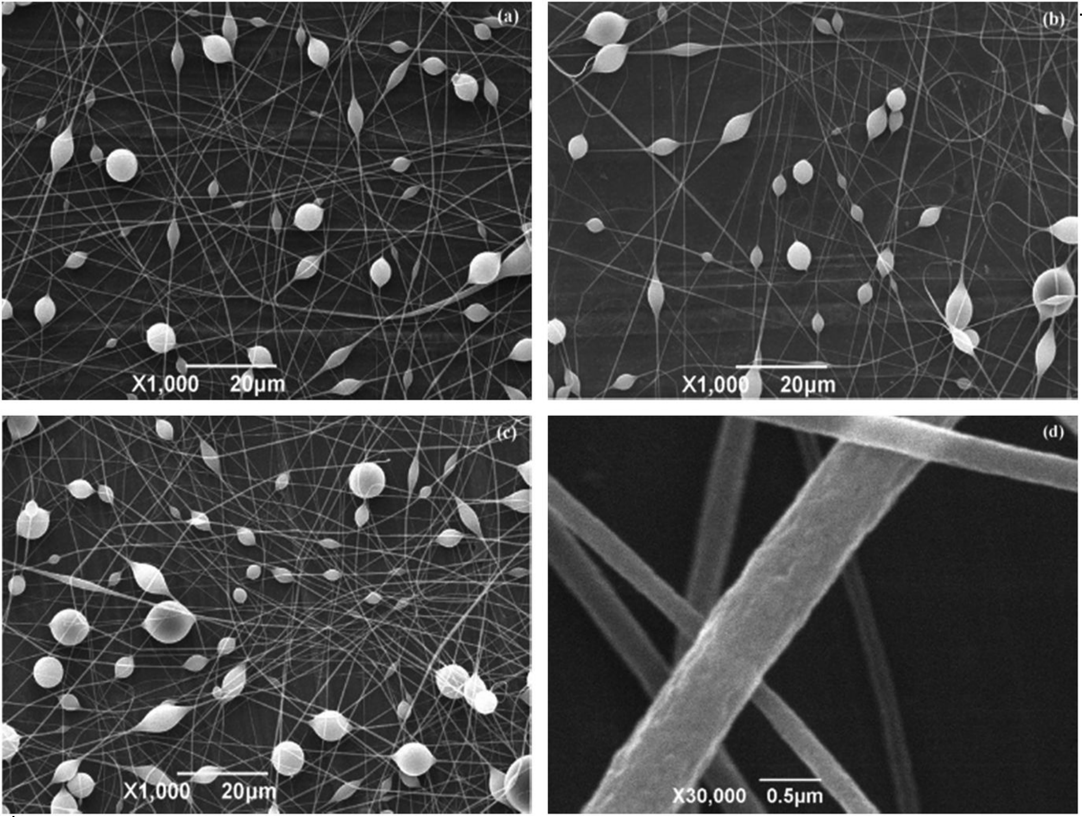

Syringe
Polymer solution
Taylor cone
Spinneret
Liquid jet
V
High voltage
power supply
Collector

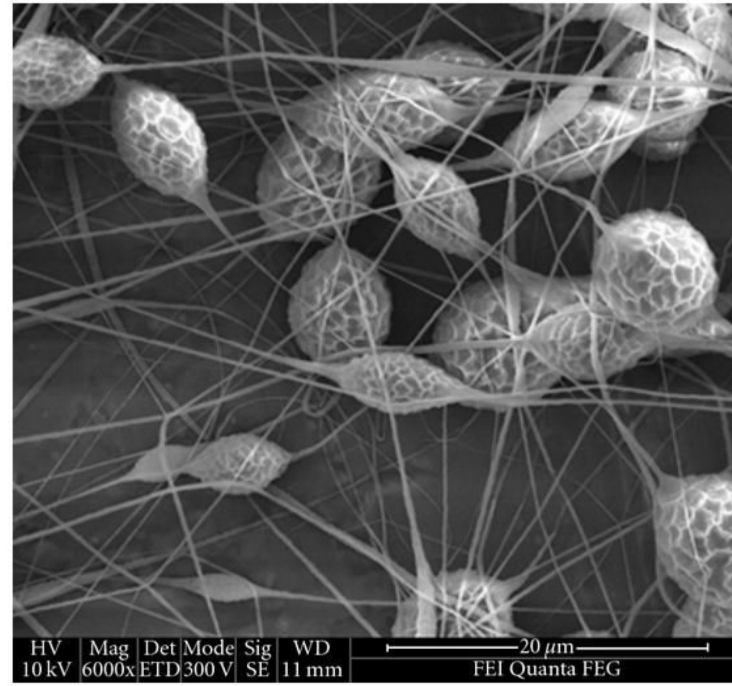

V
High Voltage
Power Supply
Metallic
Needle
Charged Jet
Translation
Rotating Collector

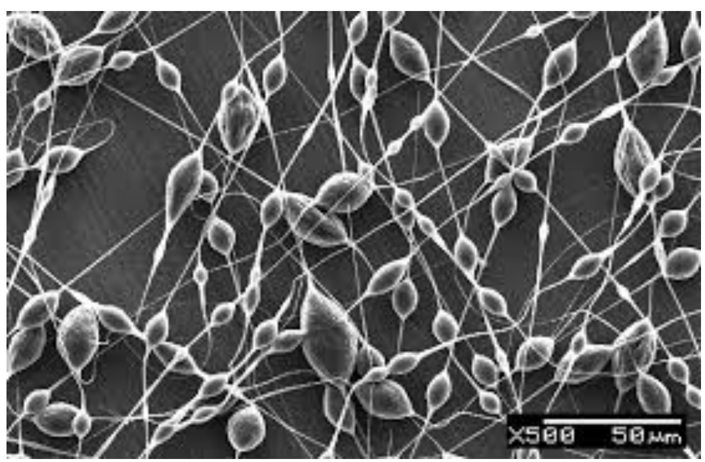


Fibre bead formation and fibre surface morphology

- colloid beads or beads-on-string fibres (necklace fibers)
- The formation of beaded fibres has been attributed to a low solution viscosity
- Increasing the polymer concentration, which results in an increase in the solution viscosity, has been the conventional approach to prevent the formation of the beads
- The addition of a small amount of ionic surfactant into the polymer solution is able to suppress the formation of beads effectively
- Bead-free and uniform fibres as a result of surfactants added to the polymer solution. No isolated beads and beads-on-string structures were found


(a)
X1,000 20µm
(b)
X1,000 20µm
(c)
X1,000 20µm
(d)
X30,000 0.5µm

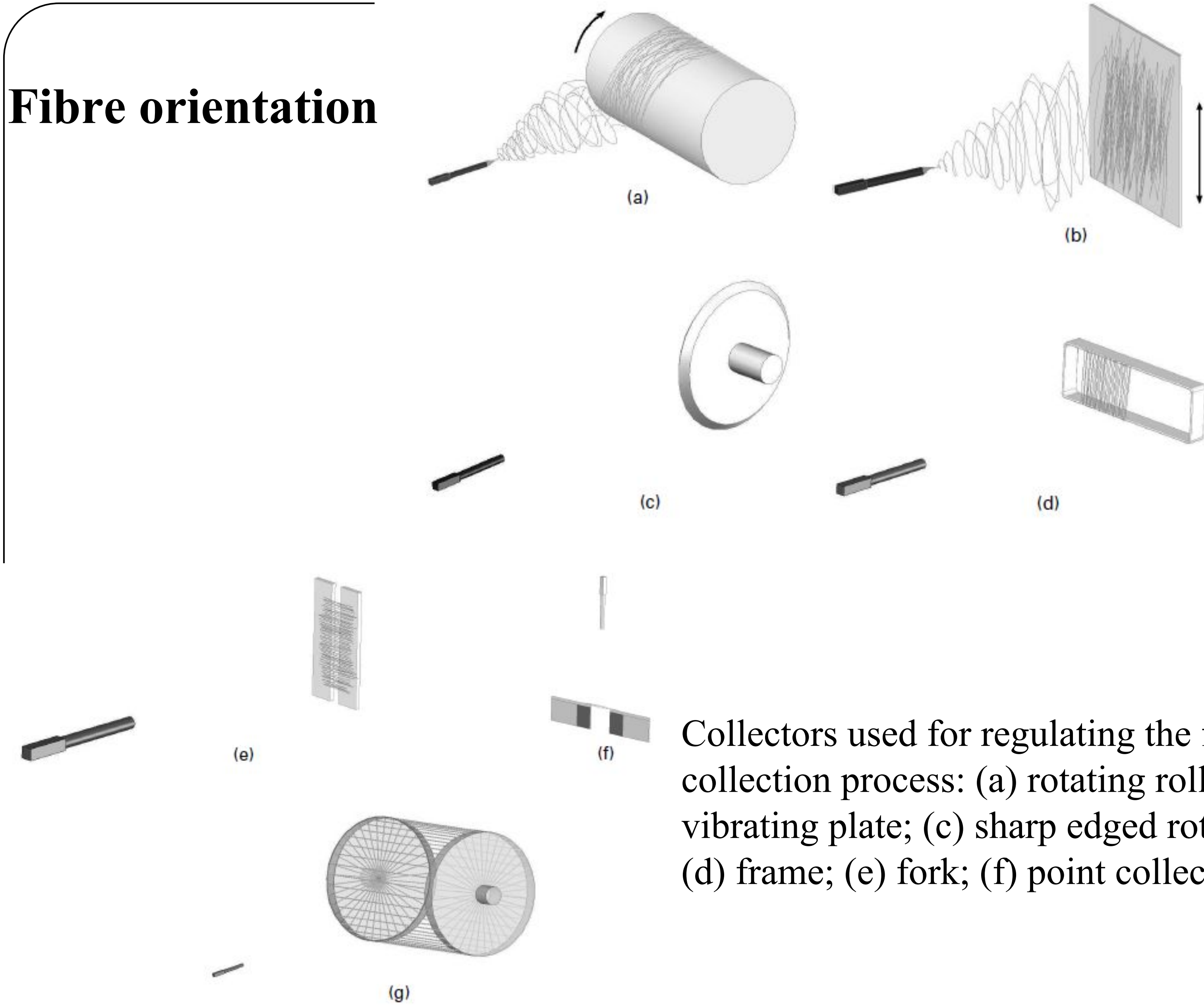

HV 10 kV
Mag 6000x
Det ETD
Mode 300 V
Sig SE
WD 11 mm
20 µm
FEI Quanta FEG


X500 50µm

Controlling fibre alignment and web morphologies

- The driving forces for the deposition of electrospun fibres come from an electric field between the charged spinneret and the grounded collector
- The deposition of the as-spun fibres on the collector is affected by the local electric potential
- The fibres or fibre sections later deposited on the collector are electrically repulsed by the previously deposited fibres. Thus they adjust their direction automatically towards an area that has a lower electric potential
- A dynamic change in the electric potential profile leads to random deposition of fibres, which results in a nonwoven fibrous web, as usually observed in an ordinary electrospinning process.
- orientated or aligned nanofibres can be formed if the fibres are deposited in a controlled way

Fibre orientation



Collectors used for regulating the fibre collection process: (a) rotating roller; (b) vibrating plate; (c) sharp edged rotating disc; (d) frame; (e) fork; (f) point collector; (g) drum

Nanofilled polypropylene fibres

Polypropylene (PP) is, besides polyesters, one of the most widely used polymers for producing synthetic fibres, especially for technical applications.

PP fibres are mostly used in different technical fields due to their excellent mechanical properties, high chemical stability and processability.

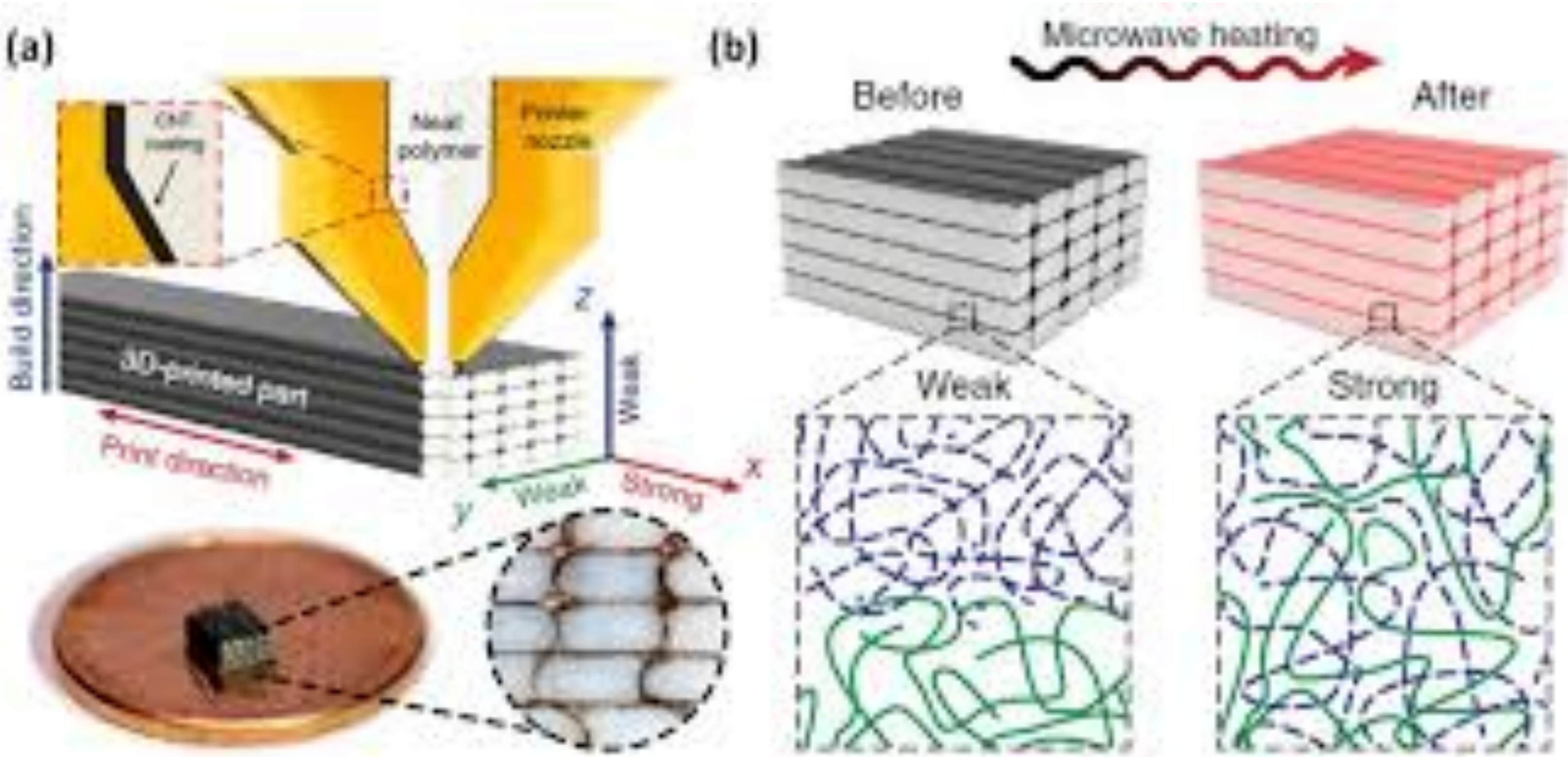
However, because of low surface energy, lack of reactive sites and sensitivity to photo- or thermal oxidation the polymer properties are insufficient for some applications.

Therefore, several techniques for fibre modification have been reported, e.g.plasma treatment, chemical modification and nanomodification, i.e. production of nanocoated and nanofilled materials.

Polypropylene (PP) fibres have good mechanical properties and can withstand temperatures up to 140 °C (softening point 140–160 °C) before melting at about 170 °C.

Low costs, good chemical resistance to acid and alkaline environments have greatly influenced the high production quantity of this polymer type.

Modifications are needed for some purposes due to PP's high hydrophobicity (moisture regain < 0.1%) and chemical unreactivity and to obtain functional materials with superior physical and mechanical properties for different applications.



(a)
Neat polymer
Build direction
3D-printed part
Print direction
z
Weak
x
Strong
y
Weak
(b)
Microwave heating
Before
After
Weak
Strong


Hydrothermal
assembly
G-Py
Pyrrole
Graphene
Aniline
CNT
In-situ
polymerization
CNT/PANI
GPCP

LOTUS EFFECT

The characteristic property of self-cleaning or so-called Lotus-Effect® surfaces is the capacity of complete cleaning only by means of water, for example, in the form of rain. The attribute is often called the self-cleaning effect, as there is no need for cleaning agents or additional mechanical support, beside the droplet momentum. The main function of nano-structured superhydrophobic surfaces in nature is most likely protection against pathogenic organic contamination such as bacteria or spores.

self-cleaning superhydrophobic surfaces

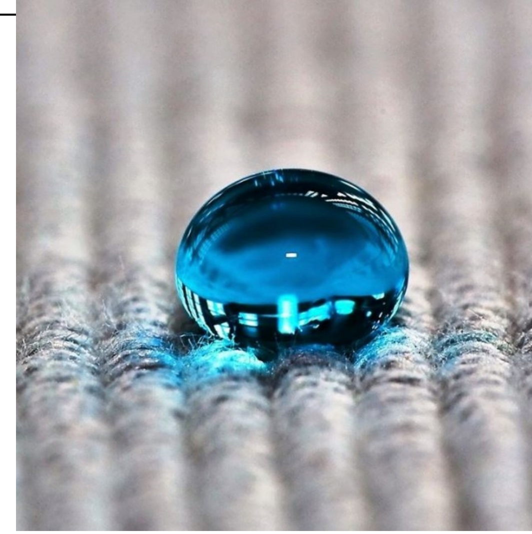
Transfer to fiber-based products

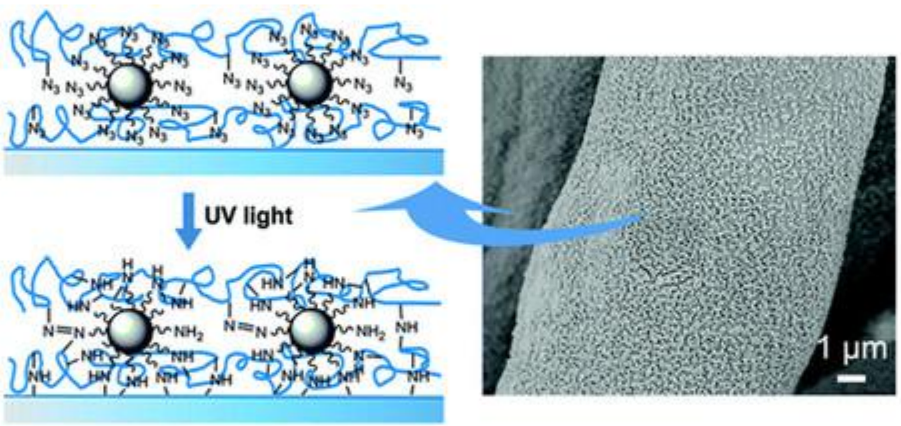
There is a variety of applications for fiber-based surfaces with self-cleaning characteristics. This includes outdoor applications, such as textile roofs for airports and railways, sunscreen textiles, outdoor clothing, but also indoor applications, which come into contact with water or water-based solutions

15.10 Honey droplet on a fabric with self-cleaning surface characteristic.

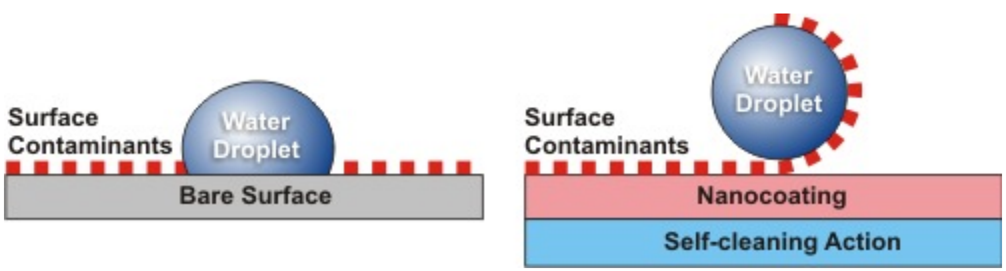
the specific features of textiles in this context is that they readily bring rough structures with at least two topological structure elements represented by the filament's fiber arrangement within the yarn structure and the yarn arrangement within the fabric structure. Subsequent approaches to implement the self-cleaning effect on textile-based surfaces also implement fiber surface modification to low surface energies, the optimization of fabric and yarn construction structures. The alteration of textile surface finishing
chemicals to meet the above-mentioned requirements can, for example, consist of polymer-based dispersions with nanoparticle additives. Other products are organic–inorganic hybrid materials on the basis of sol–gel chemistry, eventually also with nano-filler additives.


non-coated
coated
Nano-2 Super Beading Effect




UV light
1 μm


Baltic nano technologies


Surface Contaminants
Water Droplet
Bare Surface
Surface Contaminants
Water Droplet
Nanocoating
Self-cleaning Action

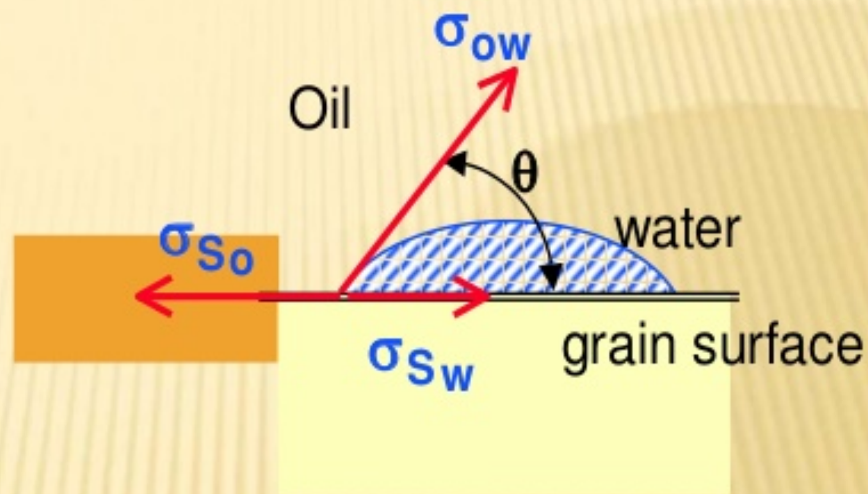
WETTABILITY & WATER ABSORPTION & STORAGE PROPERTIES

WETTABILITY

Glass is water-wet in the presence of air but air-wet in the presence of mercury.

The angle made by the interface with the solid is called the contact angle (measured through the wetting phase).

The contact angle will increase if the wetting phase is increasing (imagine a pool of water spreading over the glass plate) and decrease if the wetting phase saturation is decreasing (the pool of water being sucked away through a straw leaves a film of water behind).

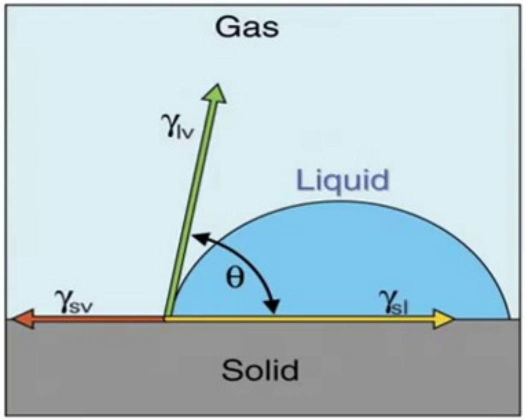


$$\sigma_{So} - \sigma_{Sw} = \sigma_{ow} \cos\theta$$

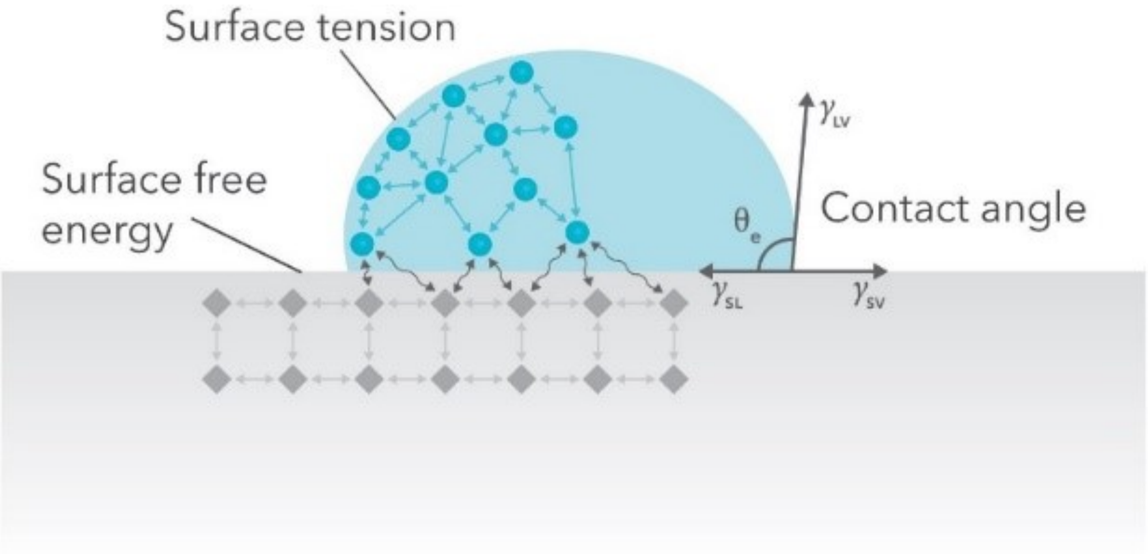
$$\cos\theta = \frac{\sigma_{So} - \sigma_{Sw}}{\sigma_{ow}}$$ Young-Laplace equation

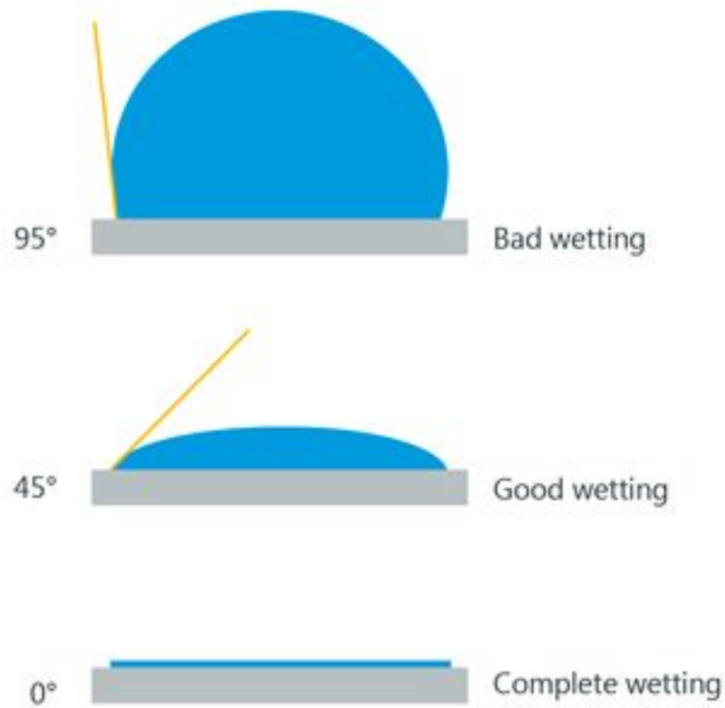
Contact Angle and Wettability

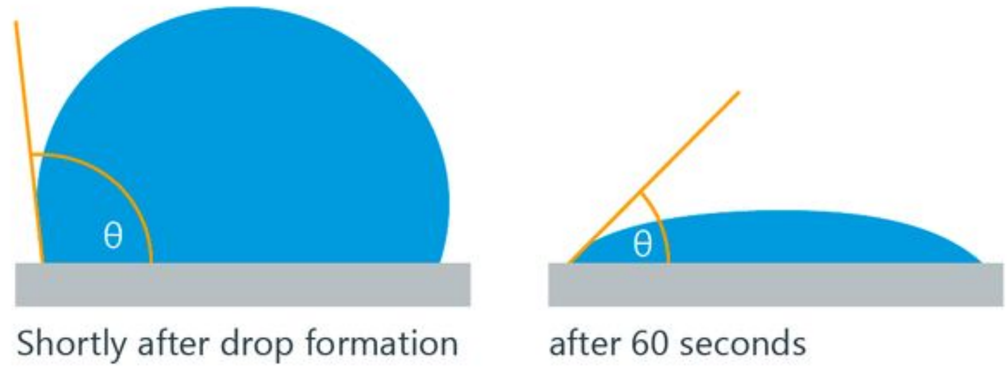
Contact angle is an angle formed by a liquid at the three-phase boundary where a liquid, gas and solid intersect.

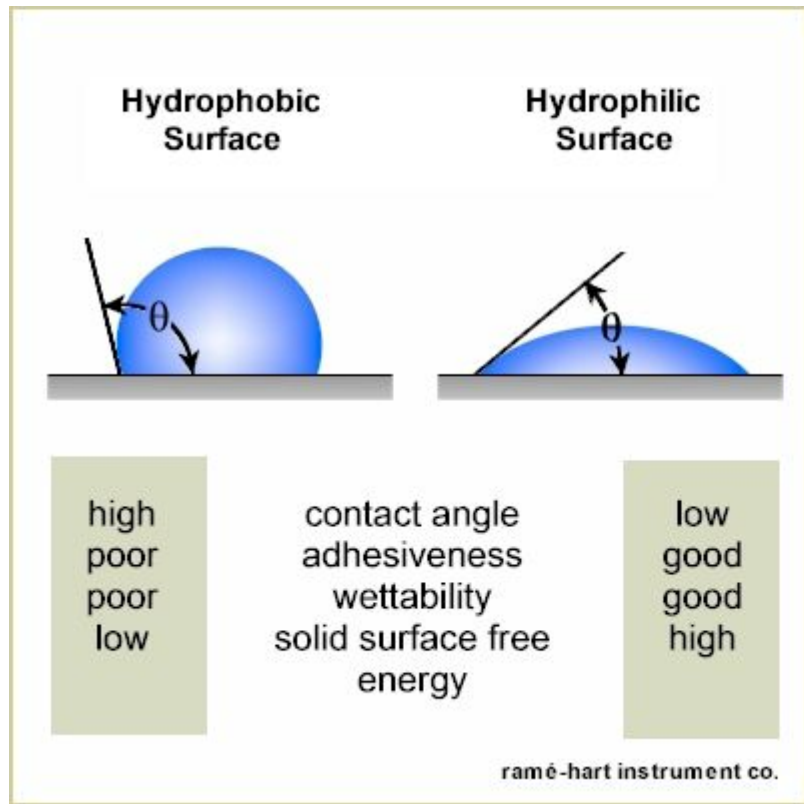


θ is the contact angle




95°
Bad wetting
45°
Good wetting
0°
Complete wetting

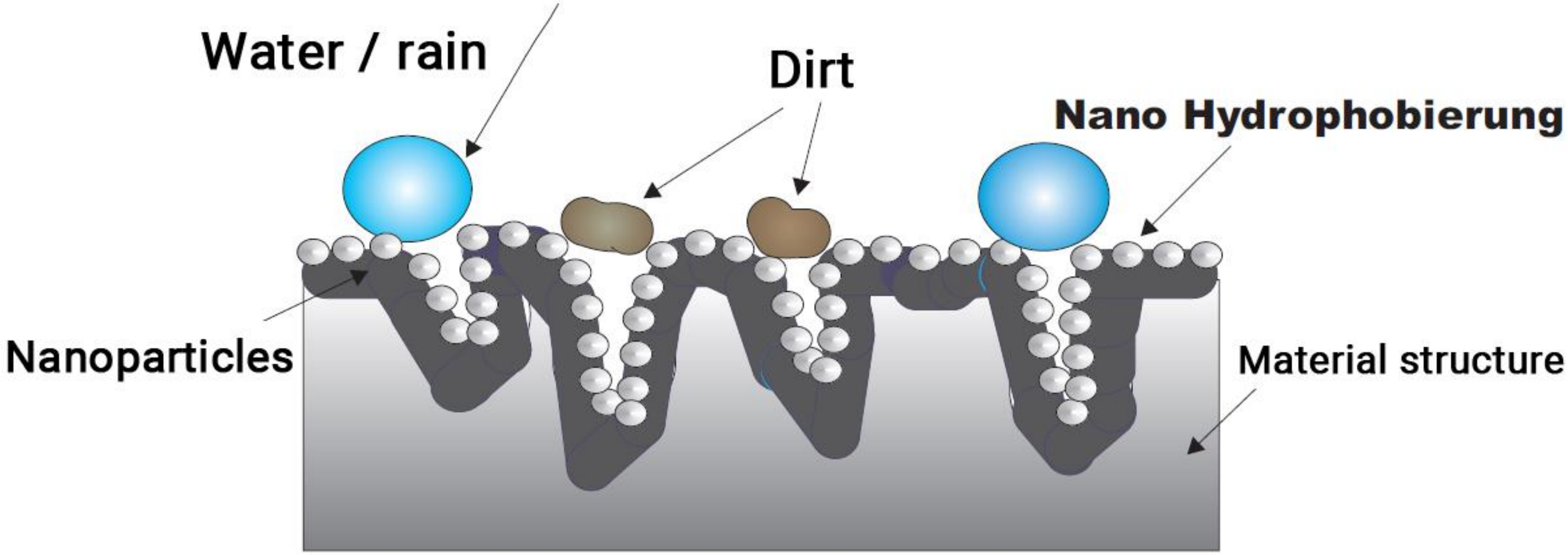

θ
θ
Shortly after drop formation
after 60 seconds


Hydrophobic Surface
Hydrophilic Surface
θ
θ
high
poor
poor
low
contact angle
adhesiveness
wettability
solid surface free energy
low
good
good
high
ramé-hart instrument co.

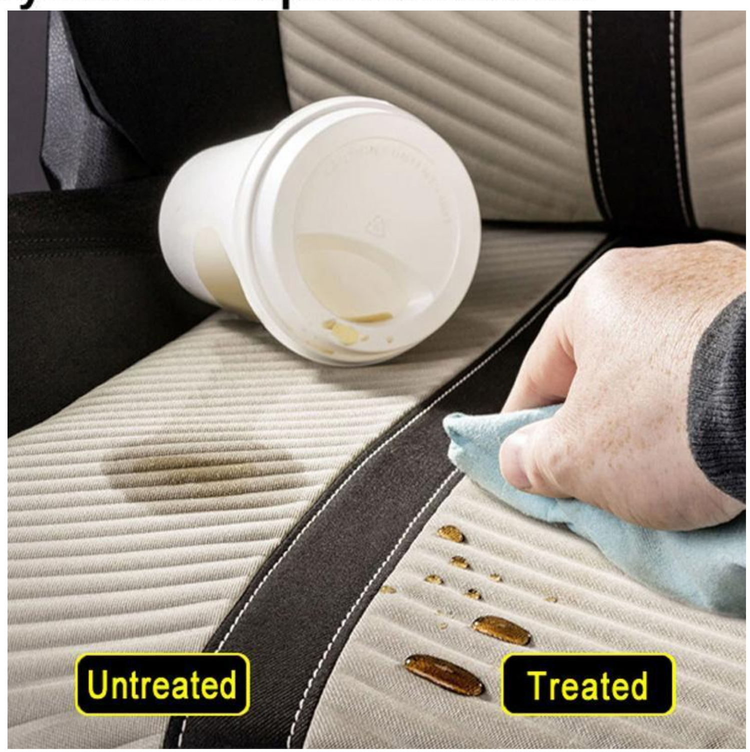
Nano Hydro Fabric Coating:

The ever-increasing demand for sophisticated fabrics with special features and exceptional comfort drives the need for the use of nanotechnology in this industry. More and more companies are utilizing ***nanoadditives*** to enhance the surface characteristics of clothes such as **water/stain-resistance, UV-protection, wrinkle resistance, color durability, flame retardancy, and better thermal performance.**

Nanofabrics are antimicrobial, strong and intelligent



Symbolic representation




Hydrophobic coating aerosol spray for fabric


Balticnano technologies
CHOOSE YOUR
NANO
HENDLEX CAR CARE SET
RENAISSANCE CARE
OFFICIAL DEALER