Introduction to Nanotechnology

- Textbook：
  Nanophysics and Nanotechnology
  by:
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Classroom: A209
Time: Thursday; 13:40-16:30 PM
Office hour: Thur., 10:00-11:30 AM or by appointment

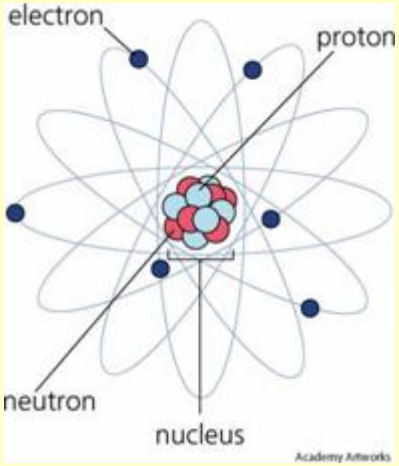
Physical-based Experimental Approaches to Nanofabrication and Nanotechnology-II

Subjects: Today class

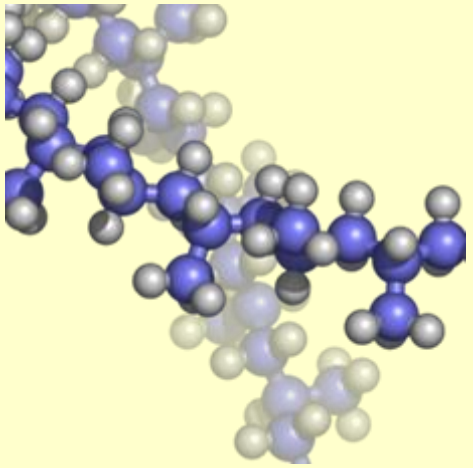
1. Fabrication of Nanofibers
2. Application of Nanofibers in Industry

Key Dimensions in Nanometers

- An atom is about 0.3 nm in size.



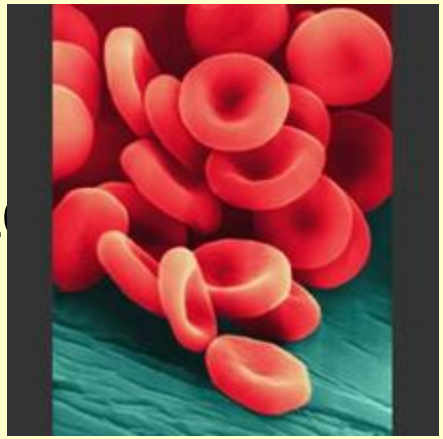
- Typical spacing between 2 carbon atoms in a molecule is 0.12 – 0.15 nm.



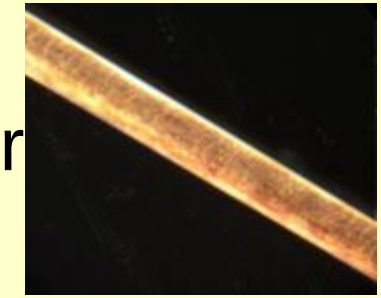
- DNA double helix has a diameter of about 2 nm.

- A bacterium of the genus Mycoplasma has a length of 200 nm.

- A red blood cell is 6,000 nm in diamet



- A human hair is 80,000 nm in diameter



- To put this scale in context, the size of a nanometer to a meter, is the same as that of a marble to the size of the Earth.

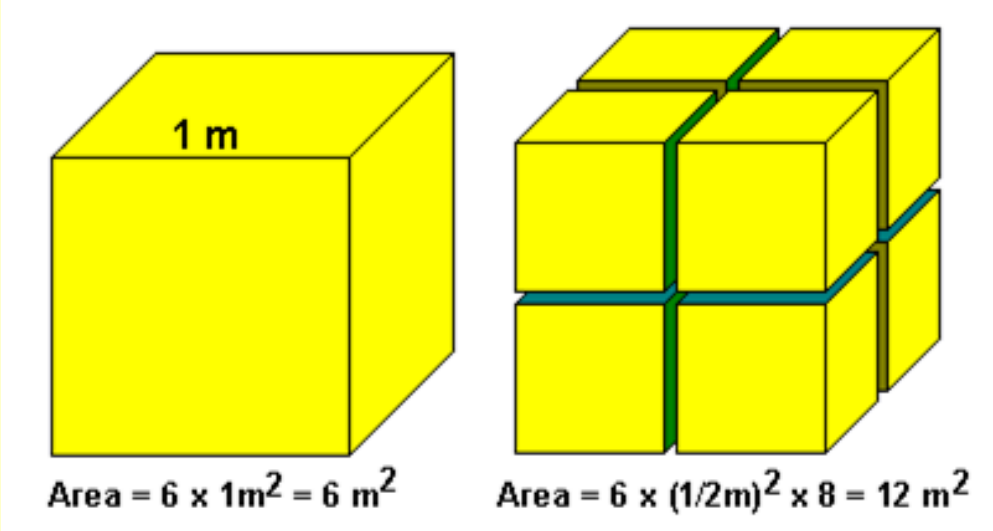
Model of Surface-to-Volume Comparisons…

Single Box Ratio

$$\frac{6\ m^2}{1\ m^3} = 6\ m^2/m^3$$

Smaller Boxes Ratio

$$\frac{12\ m^2}{1\ m^3} = 12\ m^2/m^3$$



- Neglecting spaces between the smaller boxes, the volumes of the box on the left and the boxes on the right are the same but the surface area of the smaller boxes added together is much greater than the single box.

Another Way to Think of this Ratio Using Sugar Cubes

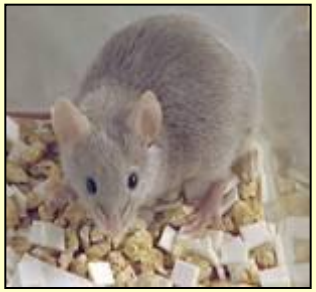
- Each individual cube is about 1 cm on a side, so each side has an area of 1 cm^2. With six sides, it has a surface area of 6 cm^2 and a volume of 1 cm^3.

  - This is a surface area to volume ratio of 6 cm^2/cm^3

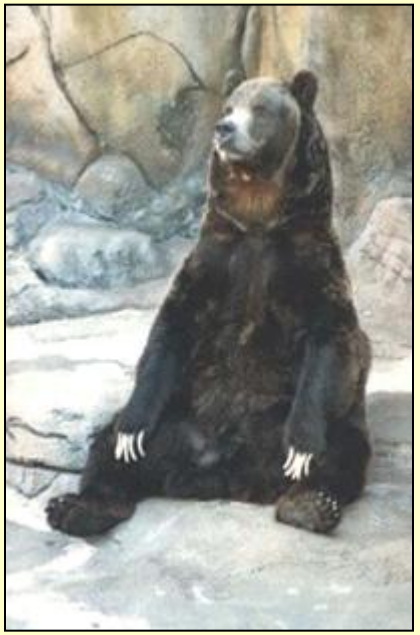
- A block made from 64 sugar cubes is 4 cm on a side and has a surface area of 6 x 16 cm^2 or 96 cm^2 and a volume of 64 cm^3.
  - This is a surface area to volume ratio of 1.5 cm^2/cm^3.

- If you compute the surface of all 64 individual cubes, you would have 64 x 6cm^2 or 384 cm^2 or 4 times more surface area with the same total volume.

An Example of the Affects of Surface-to-Volume Ratios in Animals

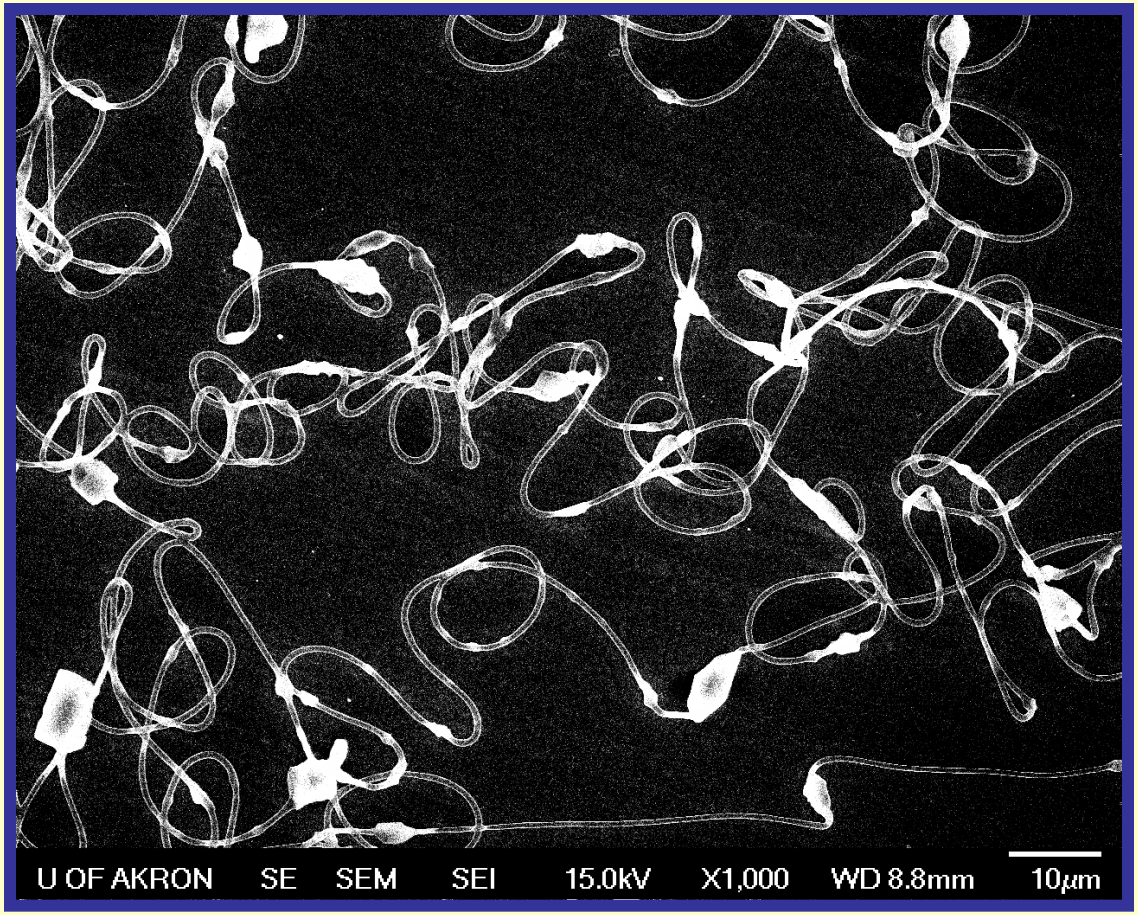


- Larger surface-to-volume ratio
  - Very susceptible to changes in heat



- **Smaller surface-to-volume ratio**
  - **Less susceptible to changes in heat**

Nanofibers:
What are they? Why are they important?



What is a Nanofiber?

- A nanofiber is a continuous fiber which has a diameter in the range of billionths of a meter.
- The smallest nanofibers made today are between 1.5 and 1.75 nanometers.
- At the right a human hair (80,000 nanometers) is place on a mat of nanofibers

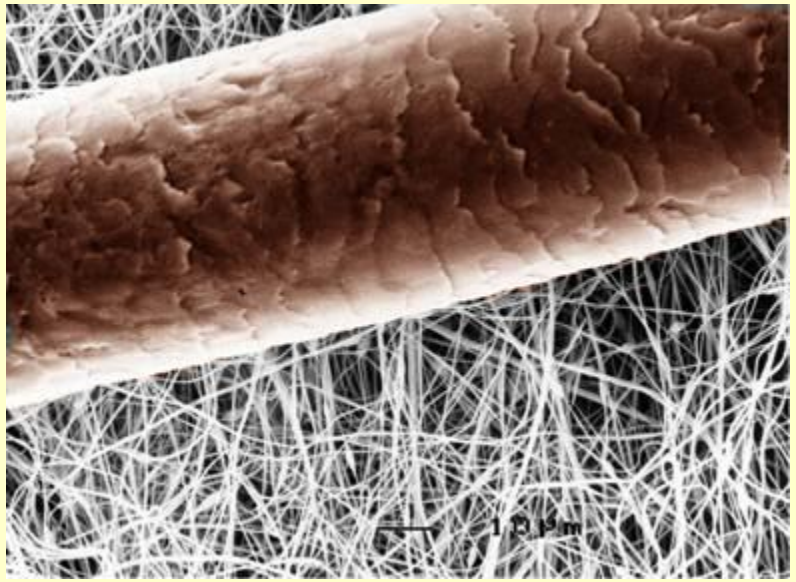
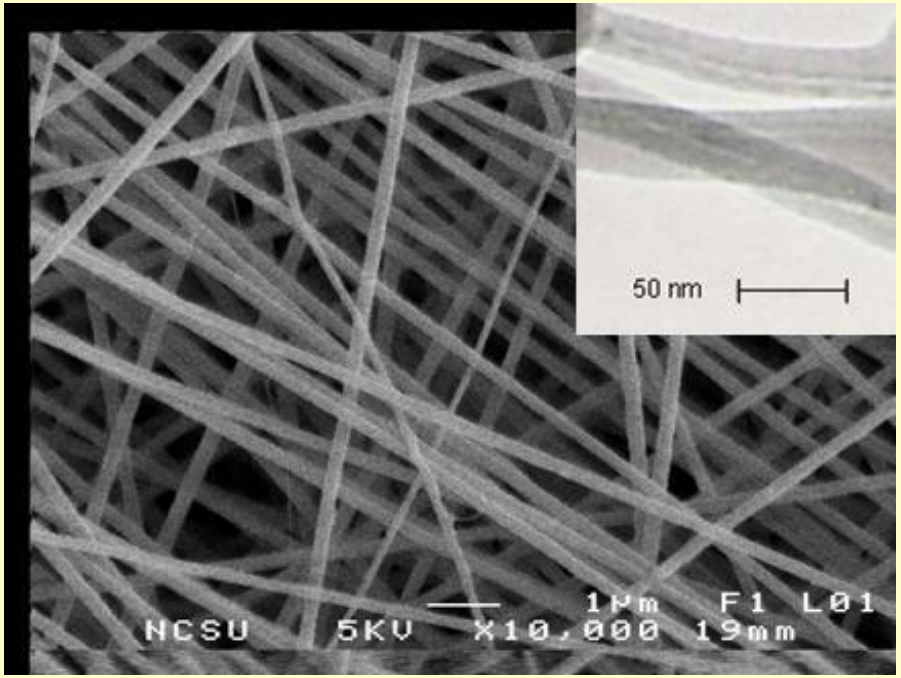


Image from EPA.gov

- Nanofibers range in diameter of 2-600 nanometers and are very difficult to see with the naked eye so they are studied using magnification…



Electron micrograph of nanofibers used for tissue scaffolds

Spider dragline 3,000 nanometers

Unique Properties of Nanofibers

- Size: nanofibers are very small which gives them unique physical and chemical properties and allows them to be used in very small places.

- Surface-to-volume ratio: nanofibers have a huge surface area compared to their volume. So scientists have lots of surface to work with!
  - The huge surface area available on a nanofiber makes it very suitable for new technologies which require smaller and smaller environments for chemical reactions to occur. Increasing the surface area speeds up a chemical reaction.

Making Nanofibers

Three different approaches toward the formation of nanofibrous materials have emerged:

1. self-assembly

2. electrospinning

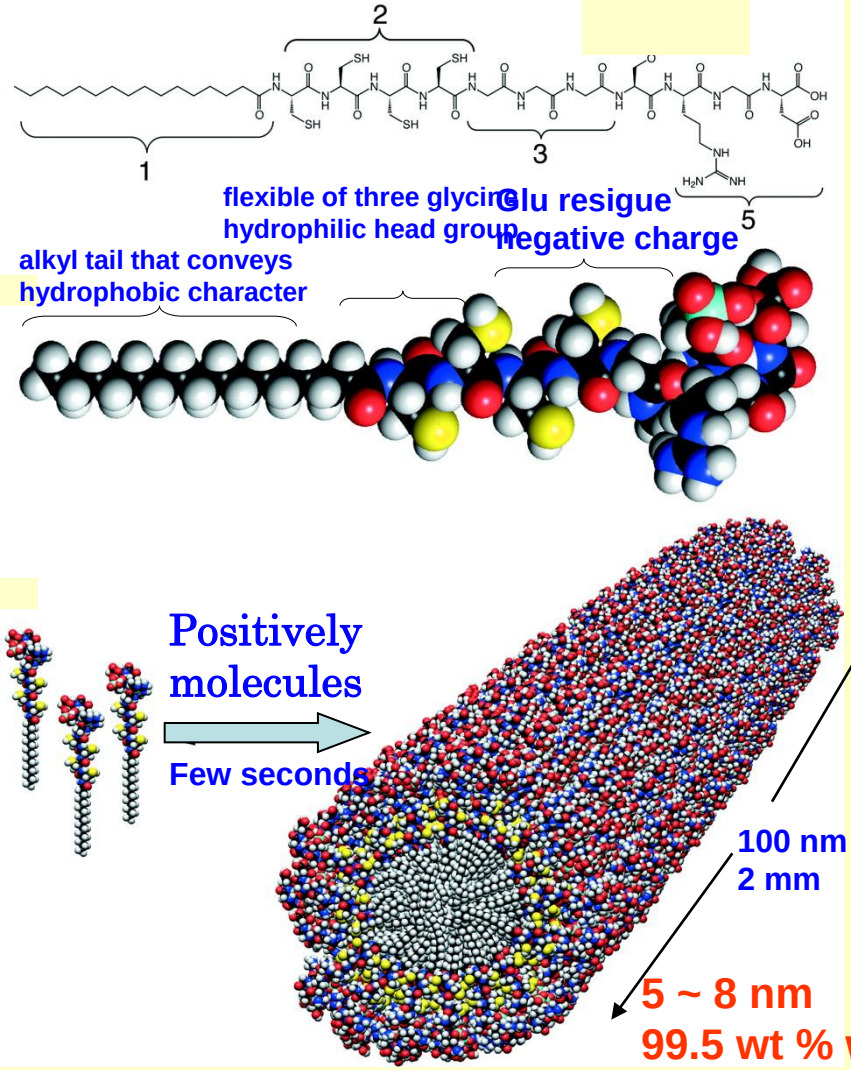
3. phase separation

Each of these approaches is very different and has a unique set of characteristics, which lends to its development as system.

1. self-assembly can generate small diameter nanofibers in the lowest range of natural materials. Self-assembly, that is, the autonomous organization of molecules into patterns or substrates without human intervention, are common throughout nature and technology. Self-assembly of natural or synthetic macromolecules produces nanoscaled supramolecular structures and nanofibers.

2. Phase separation, on the other hand, has generated nanofibers in the same range as natural materials and allows for the design of macropore structures.

3. Electrospinning has only generated large diameter nanofibers on the upper range of materials.



Peptide Amphiphiles can self assemble into sheets, spheres, rods, disks, or channels depending on the shape, charge, and environment

Amphiphiles with a conical shape in which the hydrophilic head group is somewhat bulkier than its narrow hydrophobic tail have been shown to form cylindrical micelles.
PA with mono- or di-alkyl tails were found to associate in conformations such as triple helical structures found in collagen.

High aspect ratio
High surface area

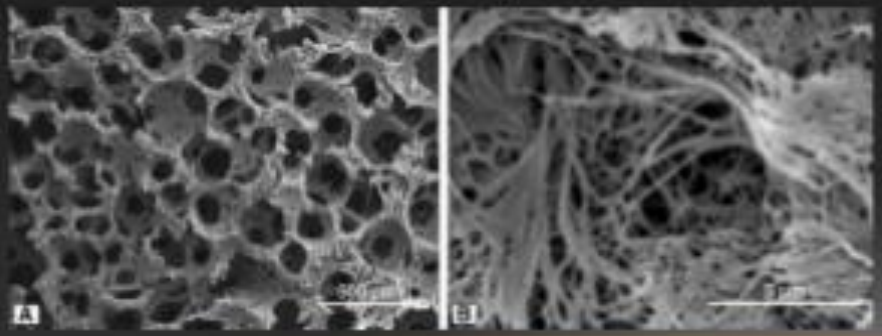
Cations can screen electrostatic repulsion among Peptide, and 3-D nonofiber are driven to assemble by hydrogen bond formation and electrostatic interactions, nonspecific van der Waals interactions, hydrophobic forces, and repulsive steric forces.

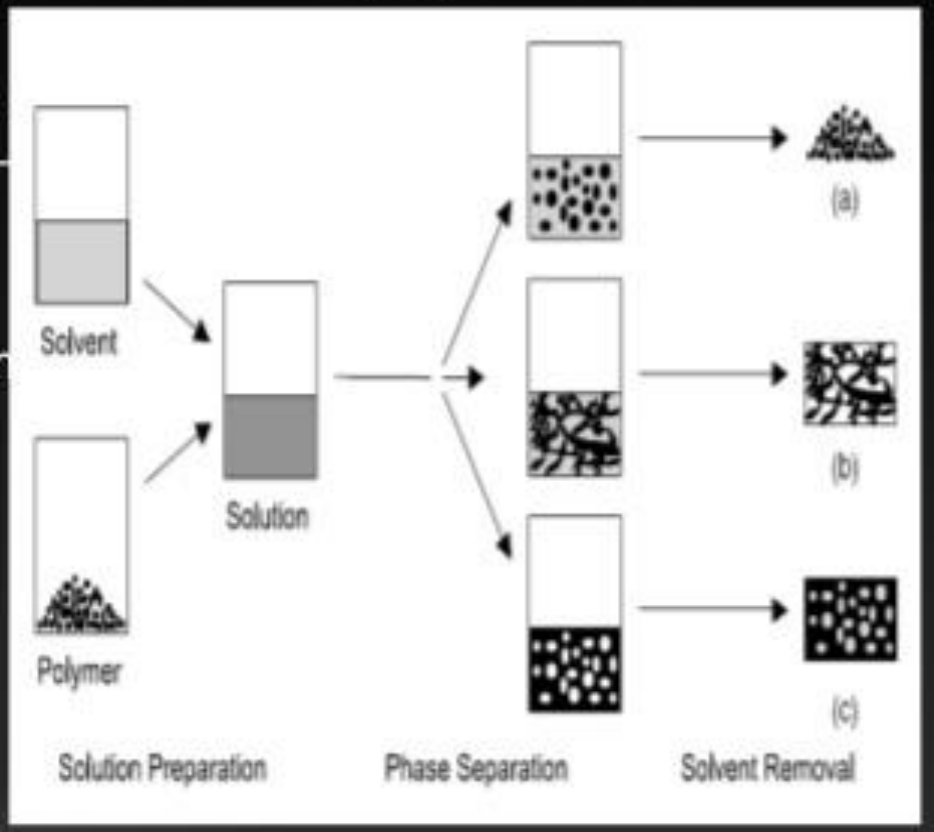
Ref: Science, Vol 303, 2004.

Phase Separation

Definition: thermodynamic separation of polymer solution into polymer-rich and polymer-poor layers

- This process involves dissolving of a polymer in a solvent at a high temperature followed by a liquid–liquid or solid–liquid phase separation induced by lowering the solution temperature
- Capable of wide range of geometry and dimension include pits, islands, fibers, and irregular pore structures
- Simpler than self-assembly





a) powder, b) scaffolds with continuous network, c) foam with closed pores.[4]

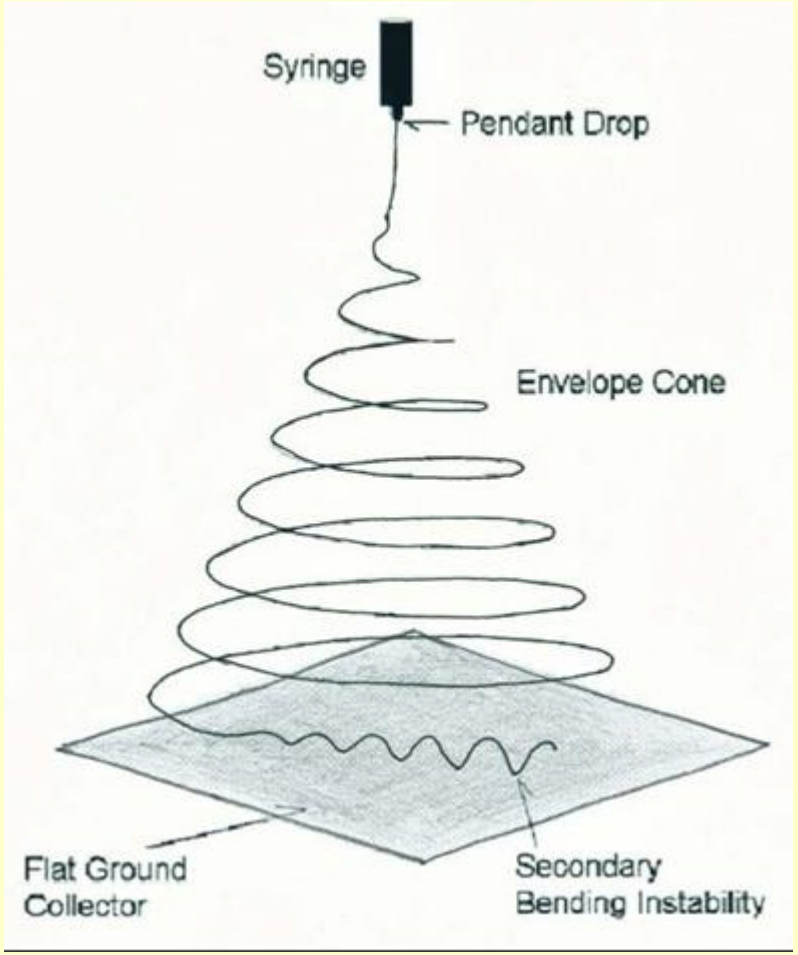
Making Nanofibers

"Melt" Fibers: some nanofibers can be made by melting polymers and spinning or shooting them through very small holes. As the fiber spins out it stretches smaller and smaller...

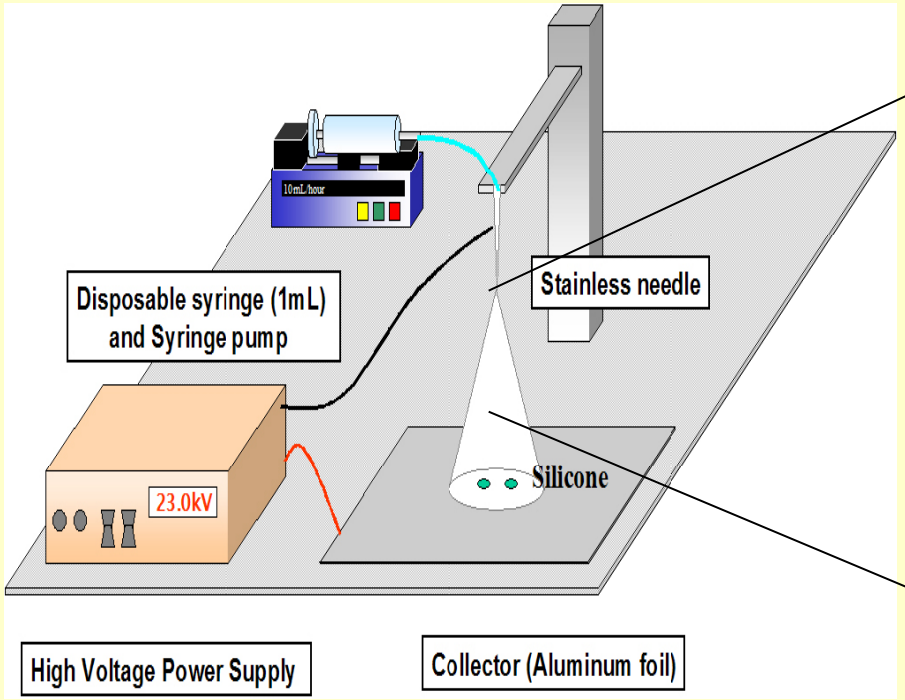
Cotton candy is made by heating syrup to a high temperature and then the liquid is spun out through tiny holes. As the fiber spins it is pulled thinner and thinner. It cools, hardens and, presto! Cotton Candy!!

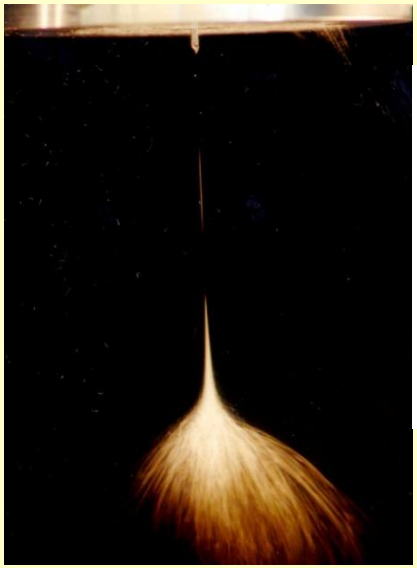
Electrospinning to Make Nanofibers

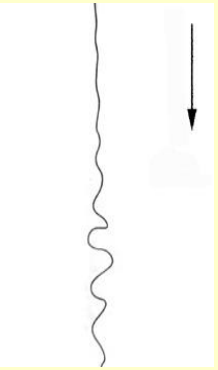
- An electric field pulls on a droplet of polymer solution at the tip of the syringe and pulls out a small liquid fiber. It is pulled thinner and thinner as it approaches the collection plate.



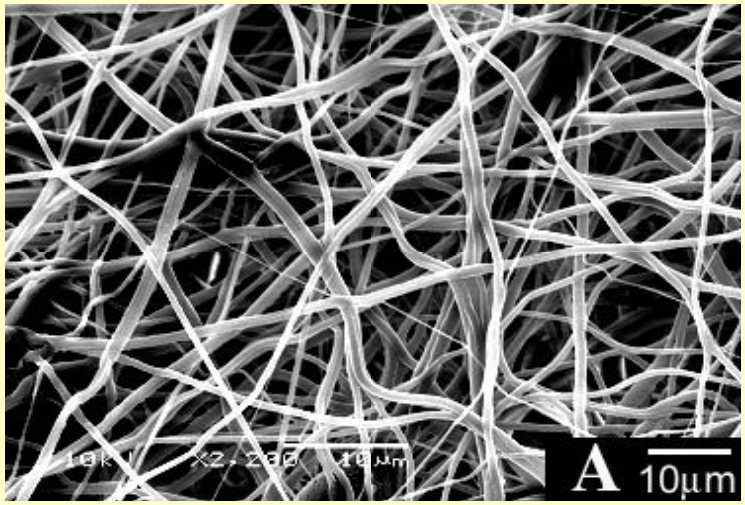
Electrospinning Apparatus



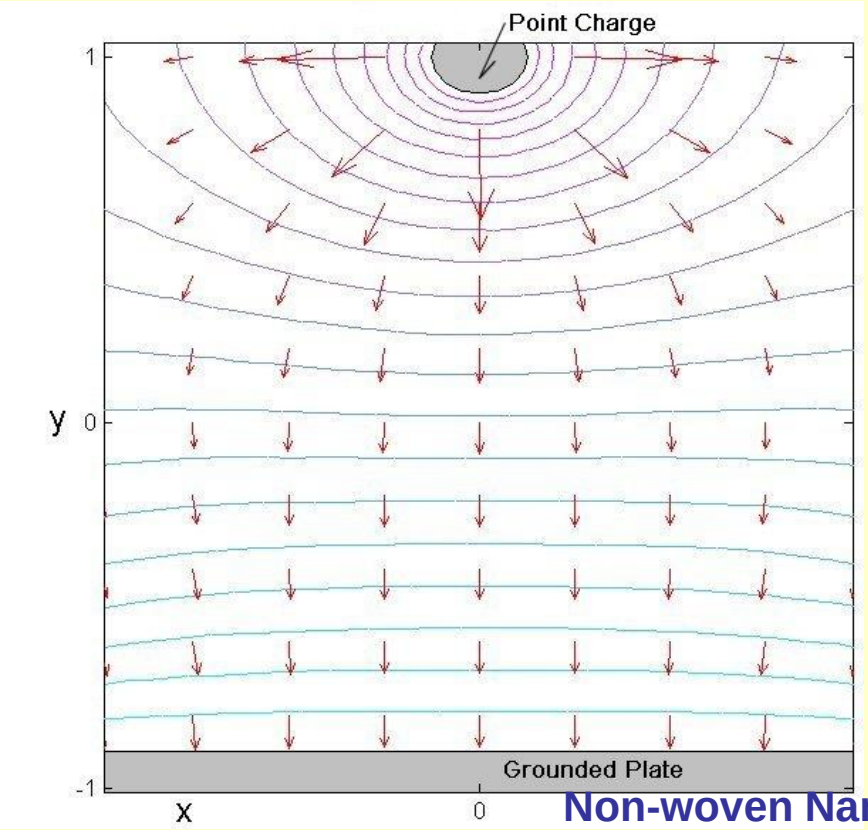




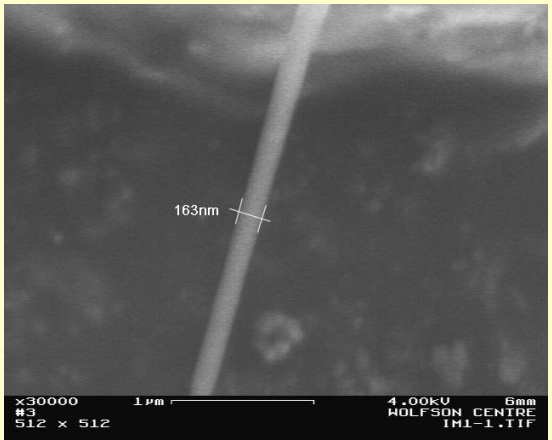
Random Nanofibers



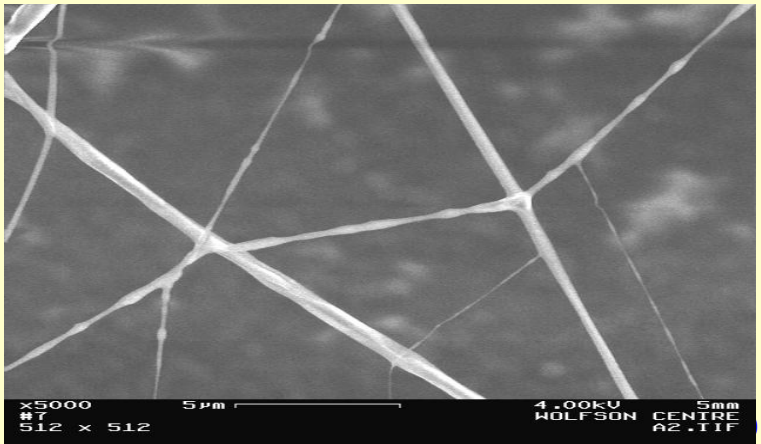
Equipotential Lines and Electric Field Lines in Electrospinning



Nanofiber (PEO)

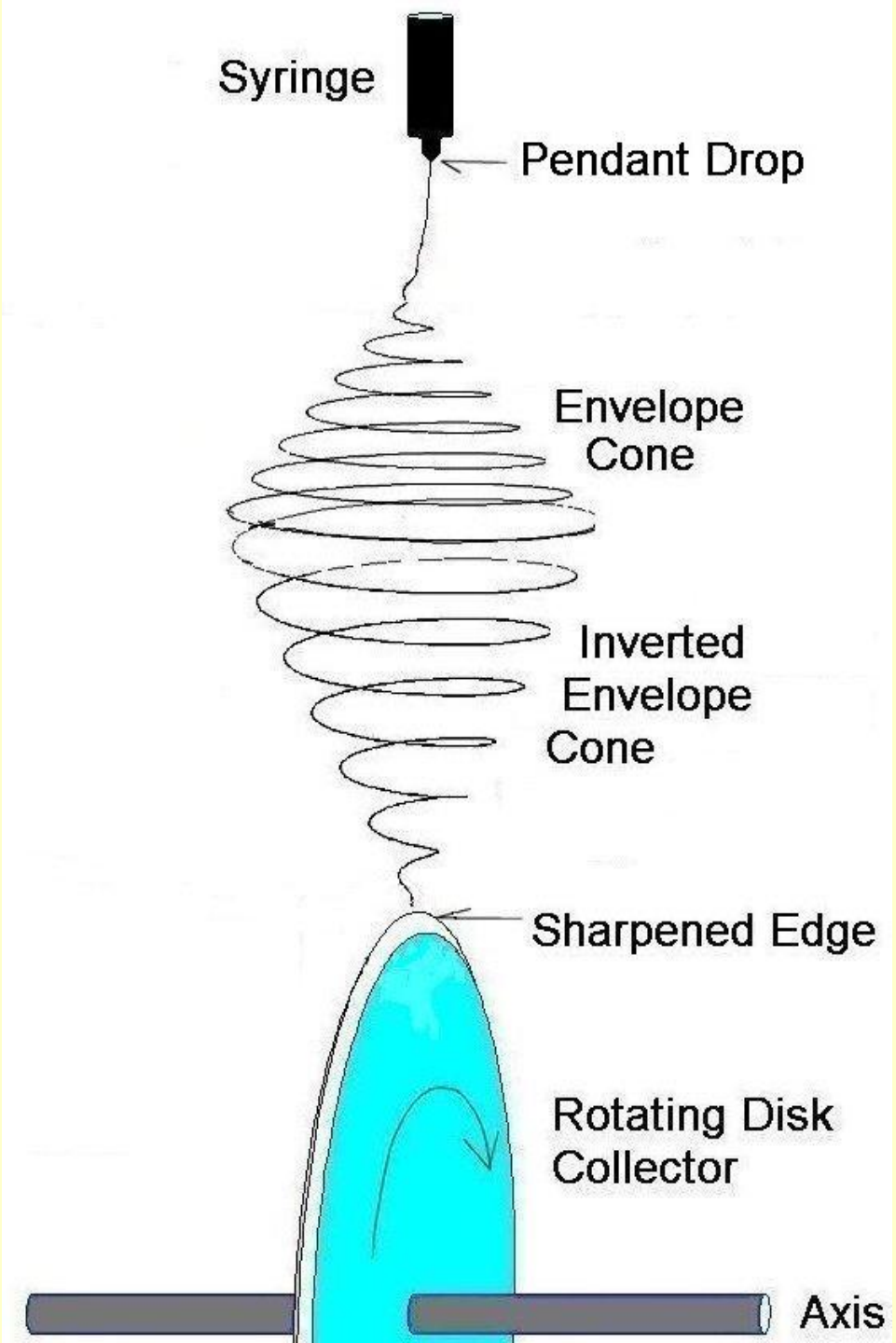


Non-woven Nanofiber Mat

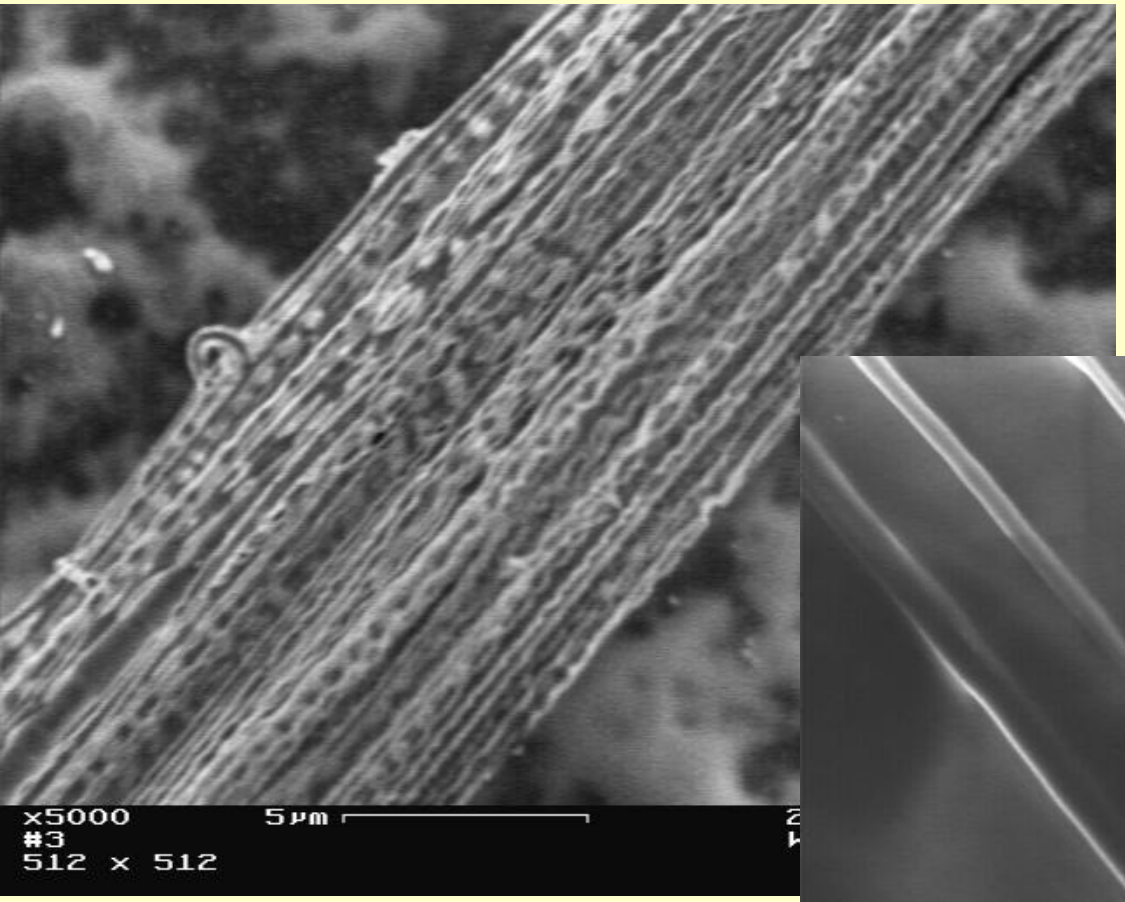


The Electrospinning Process:

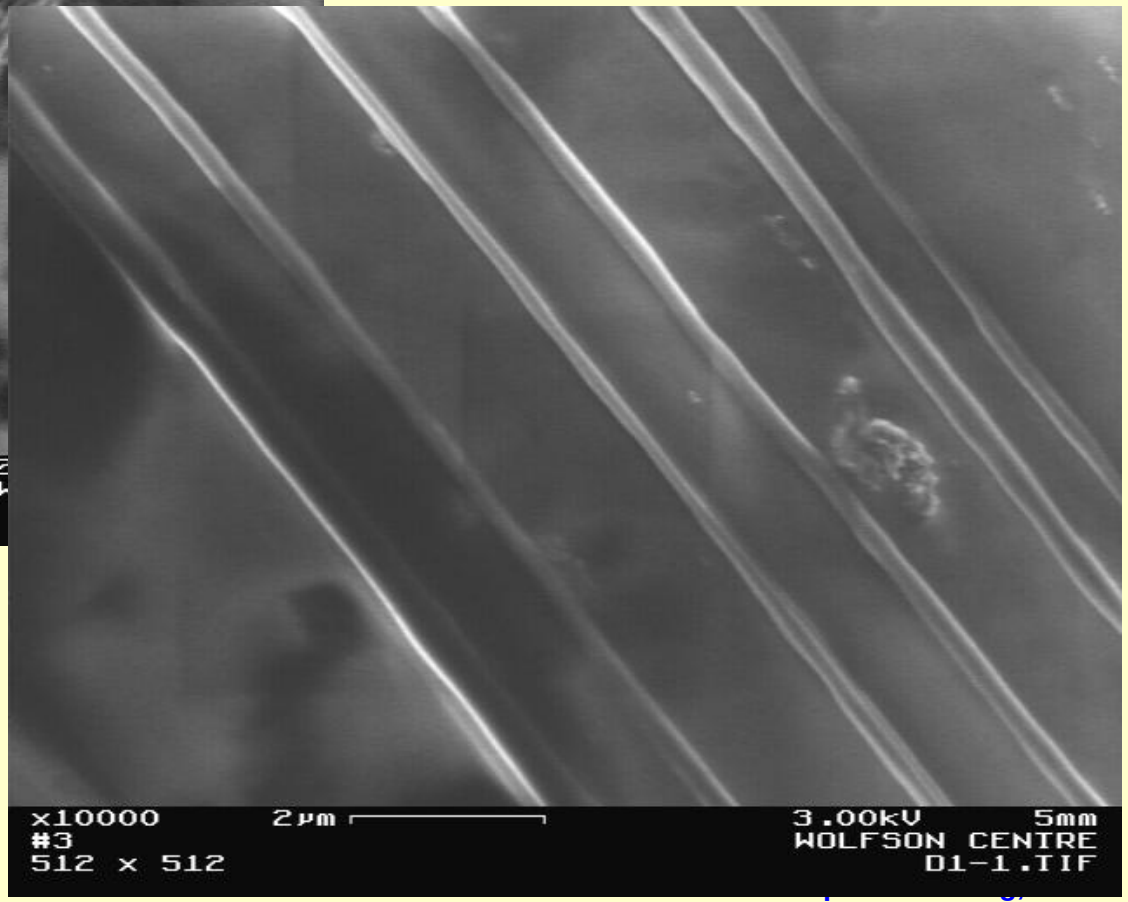
Aligned Nanofibers



Braid of Aligned Nanofibers
Density≈100nfs/μm²



Aligned Nanofibers



Electrospinning a Polymer Solution to Produce Nanofibers

- This picture shows the actual spinning of a solution made of the polymer PEO (polyethylene oxide) dissolved in water.
- Polymer solutions can be electrospun because of their long repeating units.
- The resulting fiber is collected below on a grounded plate

Image courtesy of Reneker Group
The University of Akron, College of Polymer Science

- Here you can see the individual fiber being pulled downward toward the grounded collection plate.

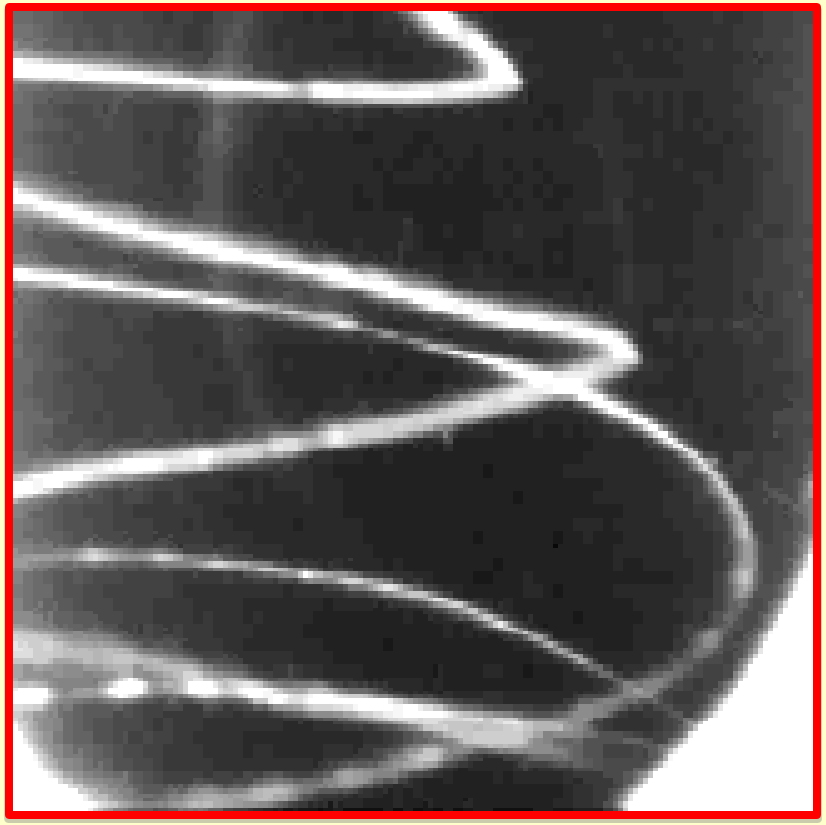
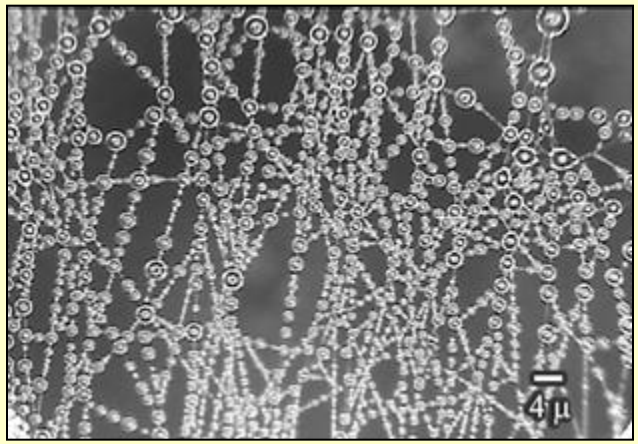


Image courtesy of Reneker Group
The University of Akron, College of Polymer Science

PEO (Polyethylene Oxide) Nanofibers

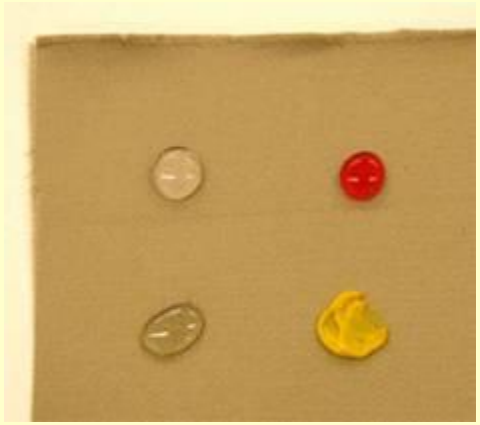
Uses of Nanofibers…

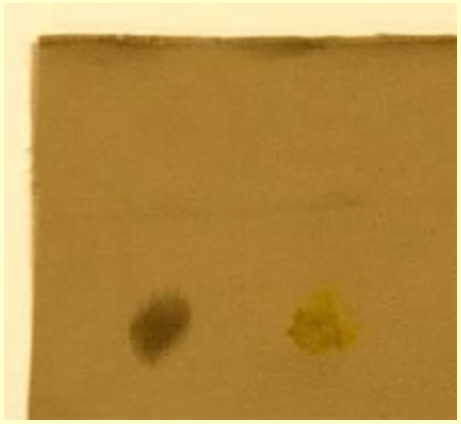
- High surface area: Filtration, Protective clothing.



Filter applications: Oil droplet coalescing on nanofibers increase the capture rate of the oil fog.

Nano-Tex fabrics with water, cranberry juice, vegetable oil, and mustard after 30 minutes (left) and wiped off with wet paper towel (right)





Uses of Nanofibers… continued.

- Support: Template for making different structures/coatings, catalysts/enzyme supports.
  - Tissue Scaffolding: Fibroblast cells grown on PLGA nanofibers.

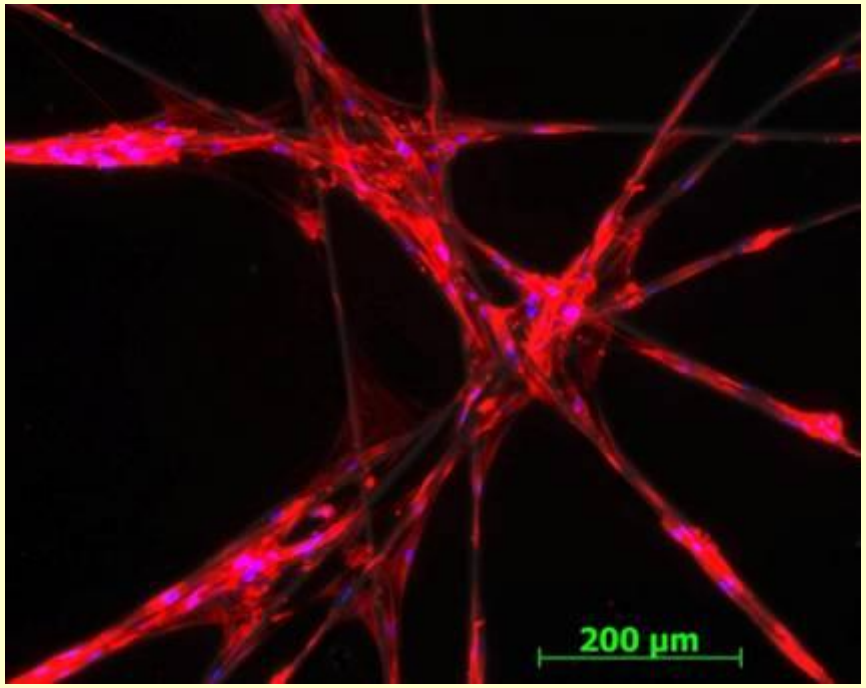


Image by Amy Liu, Hoover High School Student

Uses of Nanofibers… continued.

- Strength: Reinforced composites by nanofibers, twisted in yarns.
  - New yarns with outstanding wicking properties: Here electrospun nylon fibers are spun into yarns.

Image courtesy of Reneker Group – The University of Akron, College of Polymer Science and Samantha Loutzenheiser, Hoover High School.

Uses of Nanofibers… continued.

- Encapsulation: Drug delivery, Scaffolds for growing cells, Agriculture.
  - Water filtration: EDTA, a chelating compound, has been encapsulated in tecophilic nanofibers.
  - These fibers in a water filter can remove heavy metals, particularly lead, cadmium and copper.

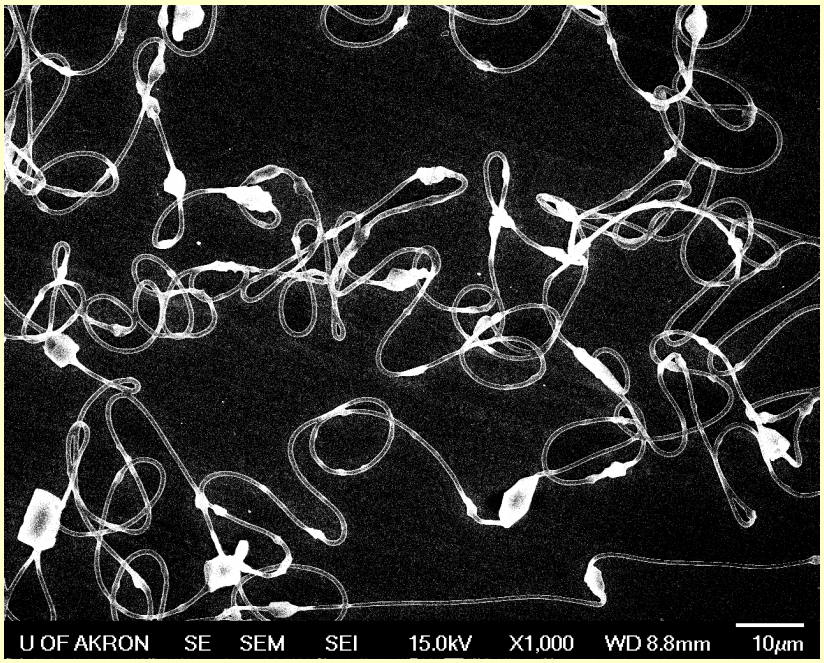


Image by Joe Sinha, Hoover High School Student

Uses of Nanofibers… continued.

- **Light Weight: Produce Solar sails in space, Aircraft wings, Bullet-proof vests.**
  - **New breathable bullet-proof vest: *Nomex* Nanofibers**

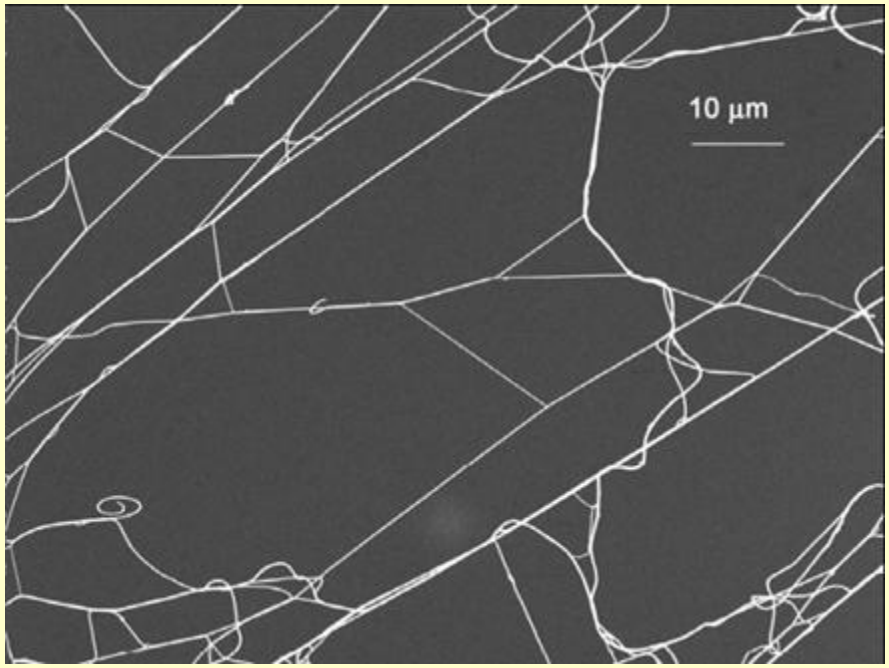
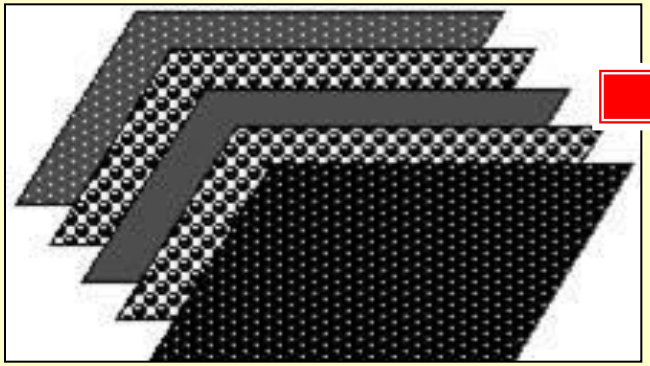
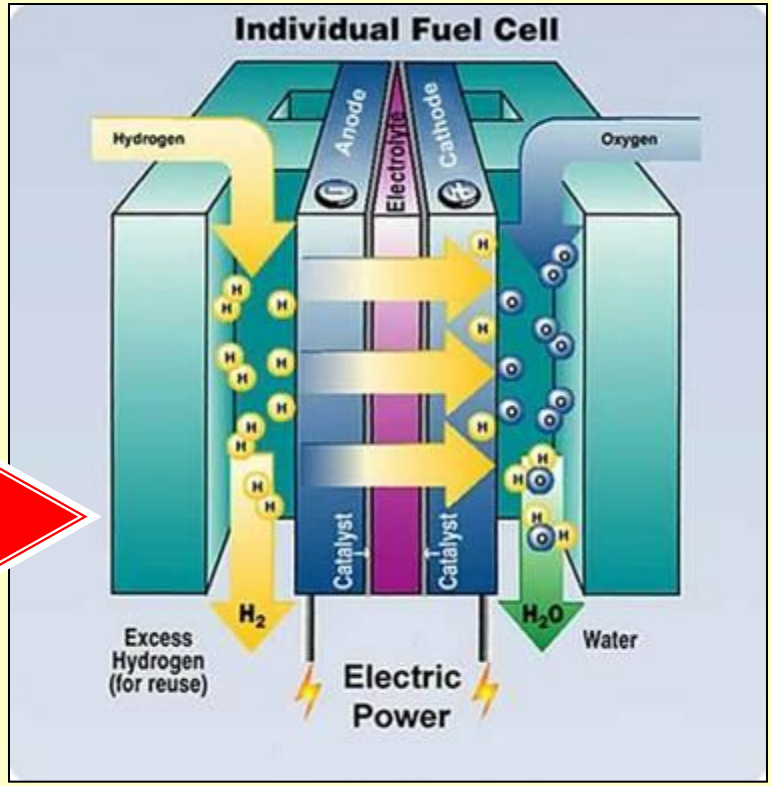


**Image courtesy of Reneker Group –
The University of Akron, College of Polymer Science**

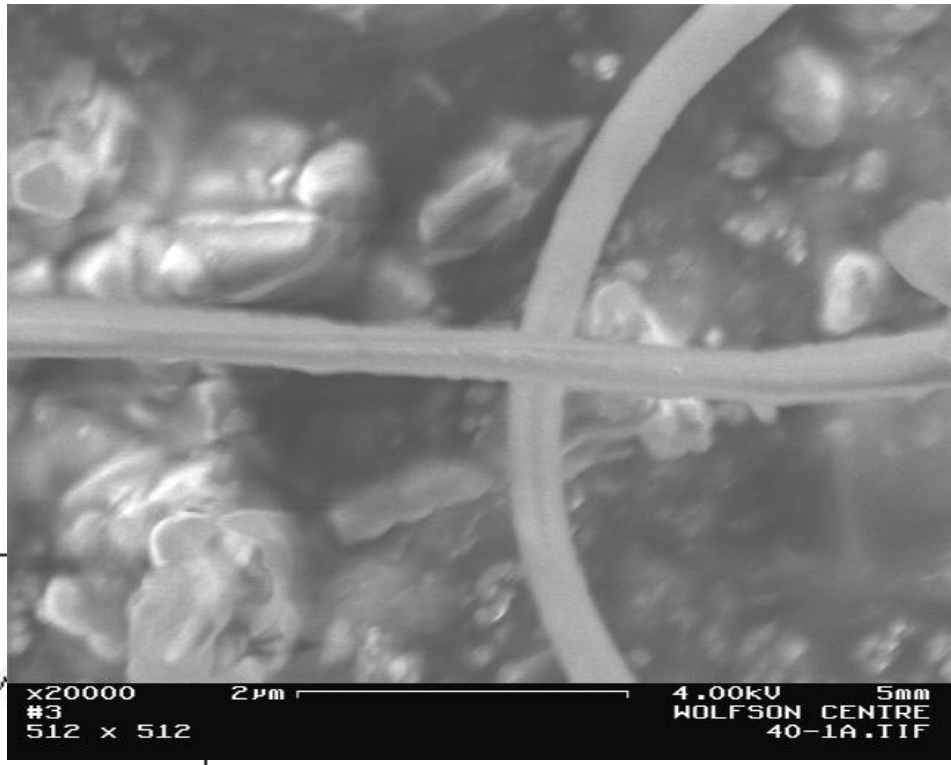
Uses of Nanofibers… continued.

- Structure: Fuel cell, Micro/Nano electronic devices
  - Nanofibers can be used to greatly decrease the size of a fuel cell while increasing the electrical output.

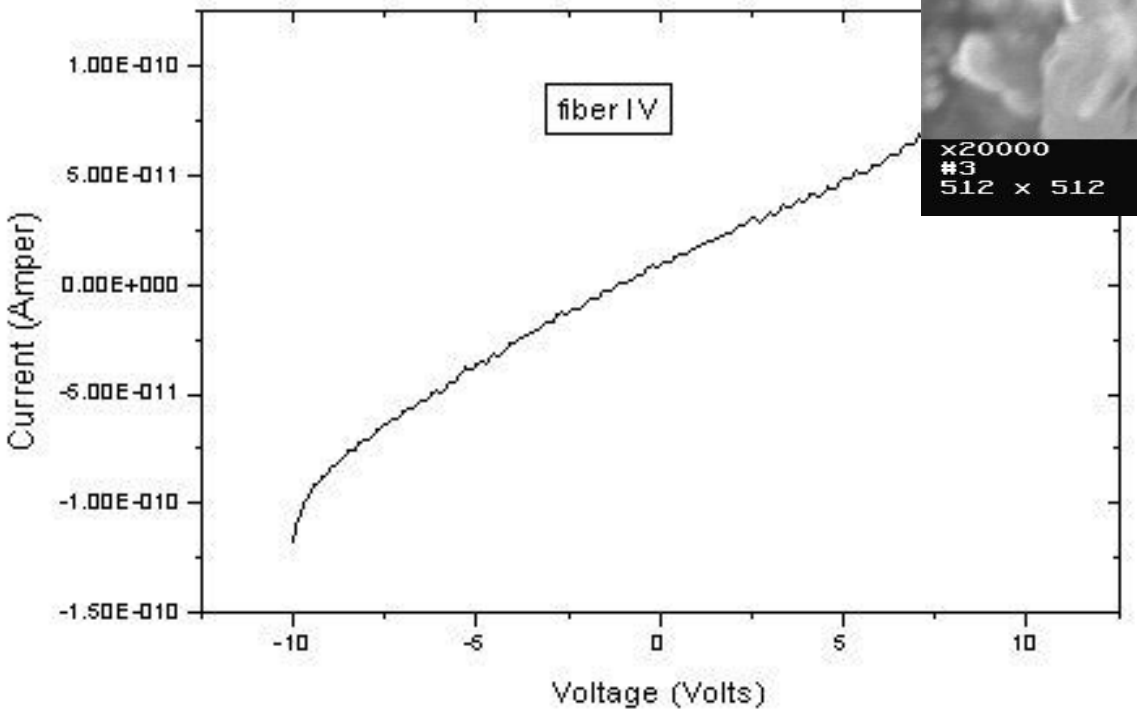




Conductive Nanofibers (PEDOT/PEO)



Current-Voltage Response



Website Resources

http://www.nanitenews.com/

http://electrospun.blogspot.com/

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

http://www.nnin.org/edunews_6.html