Centro de Física Aplicada y
Tecnología Avanzada, UNAM Juriquilla

BIOMEDICAL ENGINEERING: PAST, PRESENT AND FUTURE

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ACADEMIA MEXICANA DE CIENCIAS

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Definition of Biomedical Engineering

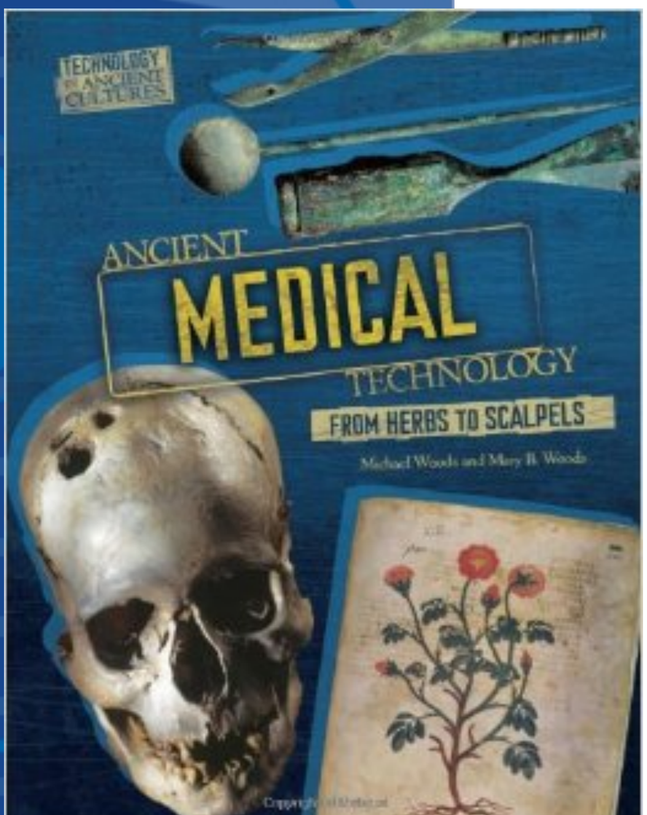
Biomedical engineering is a discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. It includes:

1. **The acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences.**
2. **The development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care delivery.**

Golden Accomplishments in Biomedical Engineering

50 Years of the IEEE Engineering in Medicine and Biology Society and the Emergence of a New Discipline

Medical instruments from the Roman Empire show that Roman doctors had many surgical skills. However, the Romans' major contribution to medicine was in public health – good plumbing kept Romans healthy!



Believe It...Or Not!

COURTESY OF THE BAKKEN LIBRARY AND MUSEUM, MINNEAPOLIS, MN

Devices to deliver electric shock for therapeutic purposes were popular in the late 18th century through the early 20th century. Top: For women, an ad for an electric corset (circa 1885) proposed cures for ailments ranging from weak backs to kidney disorders. Right: For men, an ad for an electric belt from 1902 offers a 10-day free trial.

COURTESY OF FRANCES RICHMOND, ALFRED E. MANN INSTITUTE OF BIOMEDICAL ENGINEERING

tions of telemetry. (Short-w
about 1925 and was used to
wave diathermy began after
the magnetron became availa
techniques included the ul
Svedberg) and electrophore
Tiselius), both recognized in

Electron-tube amplificatio
commercial ECG machine i
1921; this machine used an os
sitive string-galvanometer of
amplification, that made possi
from scalp electrodes. This el
was called, was developed by
in the mid 1920s, though he d
Clinical EEGs evolved in the
early 1940s. It was also in
electrocorticography—multic
brain cortex—emerged; it wa

One of the most importa
research, the electron micros
of the 1930s by two Germa
University of Berlin headed
Ruska and the oth
Reinhold Rü
transmiss
the el
pass
po

pl
beg
scope
pan had
in use as th
many as German

Radiology wa
oped application of engineeri

The Iron Lung

PHOTOS OF COURTESY OF MATTHIAS WITT, DRÄGER MEDICAL AG & CO.

The iron lung, developed in 1927 by Philip Drinker, became well known in the early 1950s for patients whose breathing capabilities were compromised by poliomyelitis. Left: A Drager E52 iron lung with electric drive from 1952. Above: An iron lung installed in a 1953 "emergency car."

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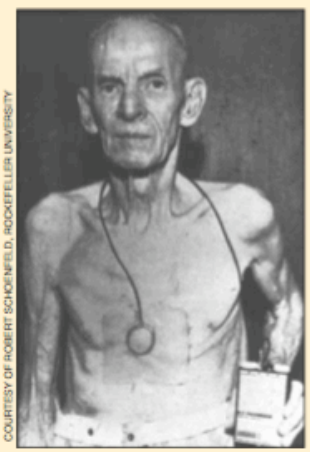
PHOTOS COURTESY OF MARK BROWN, MEDTRONIC

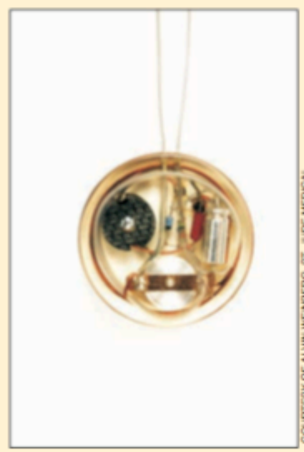
Electrical stimulation of the heart was accomplished in the late 1950s through electrodes placed in the heart muscle that were connected to an external pulse generator. Inset: The Medtronic 5800 prototype (1958) won an IEEE "Engineering Milestones" Award. Top: Dr. C. Walton Lillehei with a child who received one of the first Medtronic external pacemakers.

Pacemakers Keep the Beat



COURTESY OF ROBERT SCHOENFELD, ROCKEFELLER UNIVERSITY

A battery operated, transistorized version of a radio frequency coupled cardiac pacemaker (circa 1960). The patient has the receiver coil implanted in his chest. The external unit is connected to the transmitter coil, which is taped to the chest just above the implanted receiver coil and inductively coupled to it.



COURTESY OF ALVIN WEINBERG, ST. JUDE MEDICAL

The first implantable pacemaker was developed through collaboration by cardiac surgeon Dr. Ake Senning and Dr. Rune Elmqvist in Sweden. Arne Larsson in 1958 was the first person to receive the device. This pacemaker used two transistors and was the size of a hockey puck.

Now Hear This

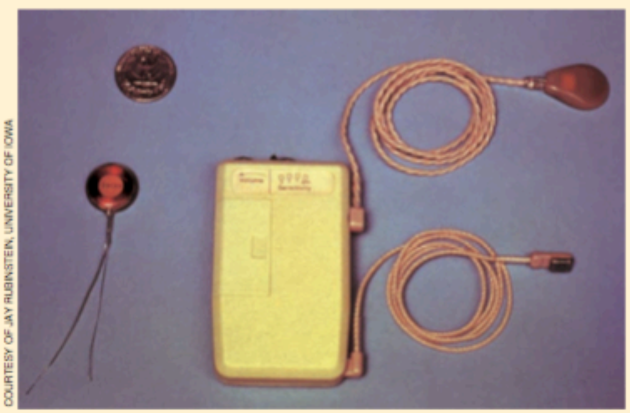
Hearing aids help the hearing impaired by amplifying sound and filtering unwanted noise. Below: An ad from 1914 shows a Mears "Ear Phone" that offered eight different sound strengths and tone adjustments. Right: This ad from the 1960s for a Zenith slip-on hearing aid is an example of aids that combined microphone, transistor, and battery into one unit that could be concealed more easily.

COURTESY OF ADNAN SHENNIB, INSOUND MEDICAL INC.; REPRINTED WITH PERMISSION OF ZENITH CORPORATION

COURTESY OF ADNAN SHENNIB, INSOUND MEDICAL INC.

COURTESY OF THE BAKKEN LIBRARY AND MUSEUM, MINNEAPOLIS, MN

The Sonotone 1010 was an important transitional hearing aid because it mixed transistors and tubes. In 1953 it won the First Annual Audio Engineering award for technical excellence in hearing aids.

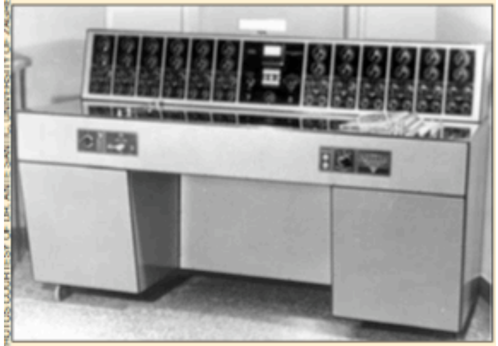


COURTESY OF JAY RUBINSTEIN, UNIVERSITY OF IOWA

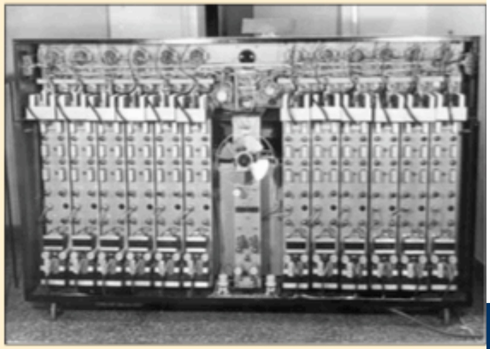
Different from hearing aids, cochlear implants stimulate the auditory nerve. This House-3M cochlear implant was the first device to prove that electrical stimulation of the human ear could provide beneficial speech information to the deaf. Despite the fact that modern multichannel implants provide much more speech information, there are still many people using the House implant who derive substantial benefit.

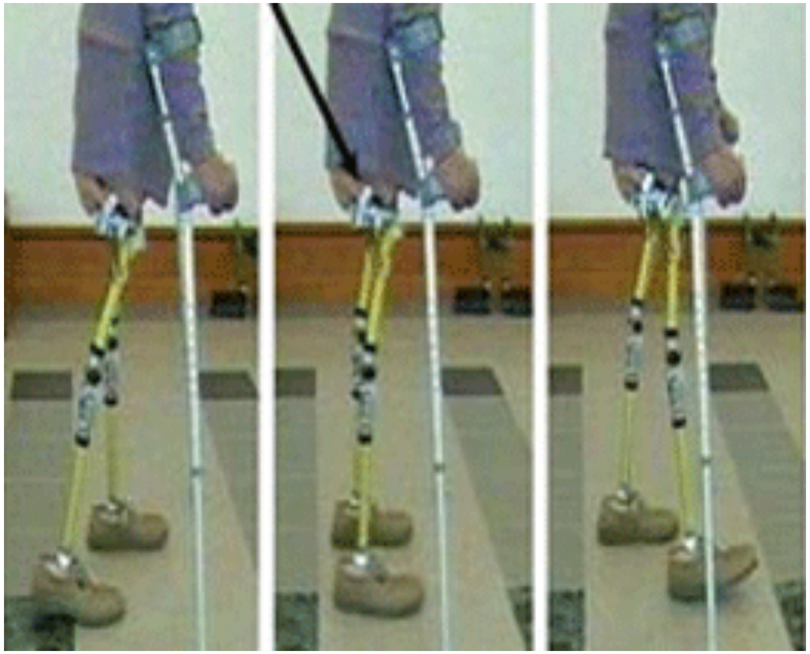
The Lab Goes High-Tech

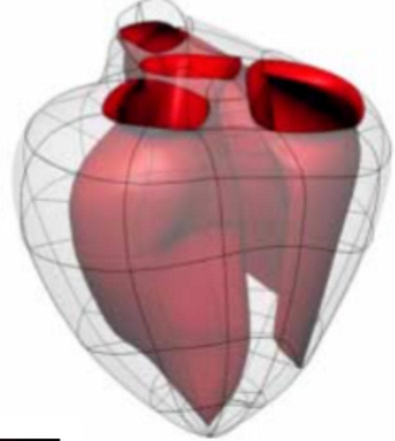
The first decade where bioengineers routinely had access to computers was the 1960s, and there seemed to be countless ways computers could assist in research and health care. Above: Dr. Irving Engelson is shown in 1960 standing near the Electroencephalographic Statistical Analyzing Computer (ESAC), which he designed and used for electroencephalograph studies.



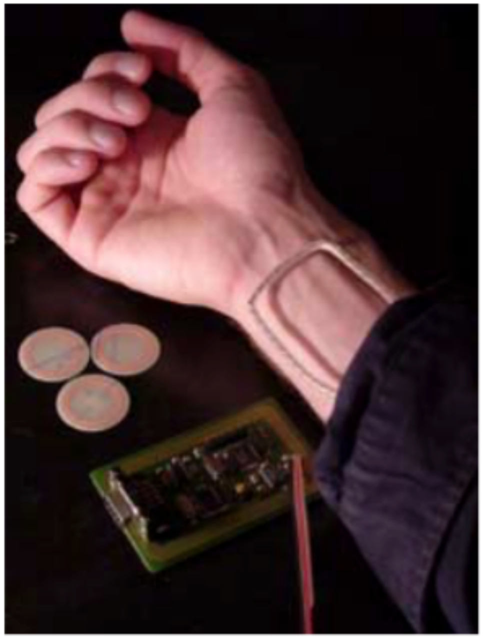
Front (above) and rear (below) views of a 12-channel electroencephalograph developed in Southeastern/Central Europe in 1960 at the Institute of Electrical Engineering in Zagreb, Croatia.



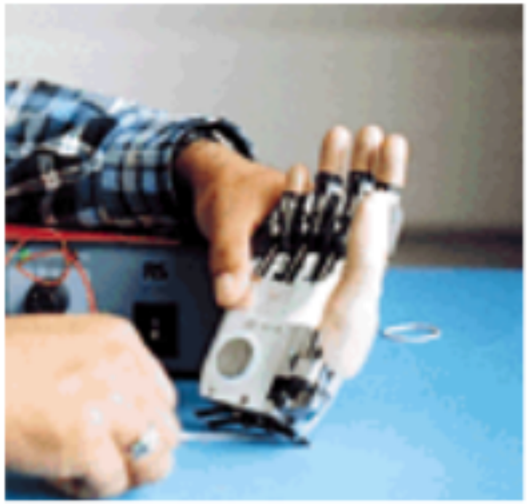




Defibrillator for in-hospital use, designed by IDEO London for Artema, 1998. Photo courtesy IDEO.

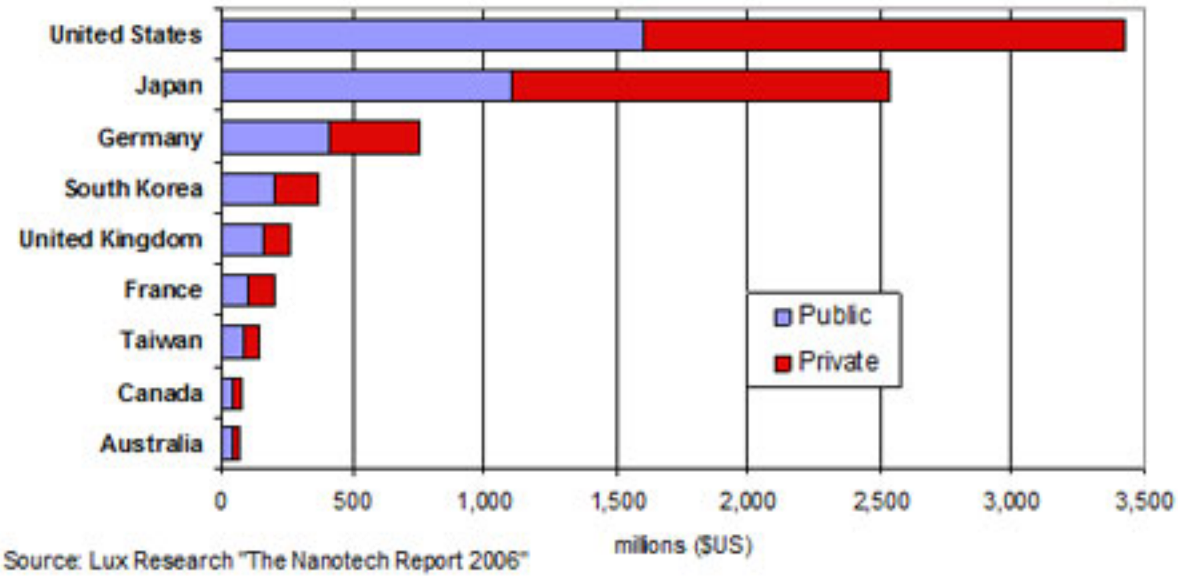


Wearable computers can play a role in making health care delivery possible for anyone, anyplace, anytime. Photo courtesy Faustina Hwang.



New devices with the latest technology can make a dramatic difference in people's lives.

Mini-infusion pump transdermal medicine-delivery device, designed by IDEO for Pharmetrix. Photo courtesy IDEO.


United States
Japan
Germany
South Korea
United Kingdom
France
Taiwan
Canada
Australia
Public
Private
0
500
1,000
1,500
2,000
2,500
3,000
3,500
millions ($US)
Source: Lux Research "The Nanotech Report 2006"

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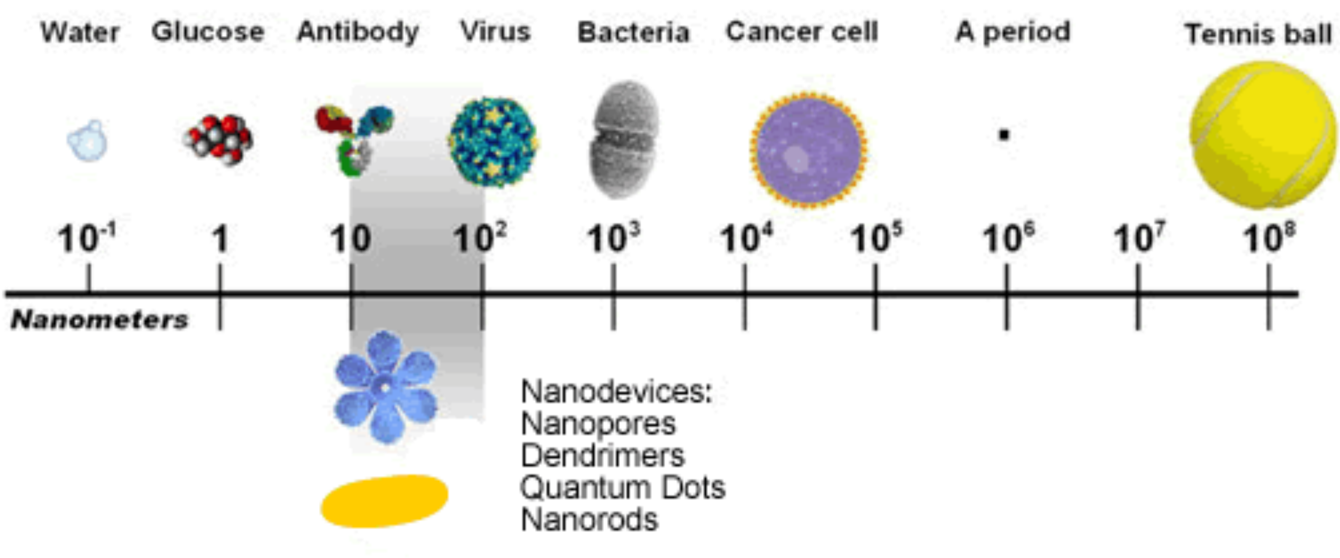
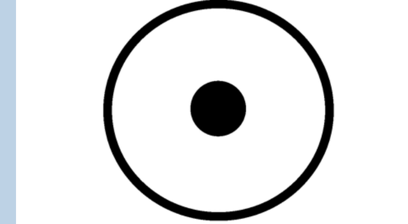

Water
Glucose
Antibody
Virus
Bacteria
Cancer cell
A period
Tennis ball
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
Nanometers
Nanodevices:
Nanopores
Dendrimers
Quantum Dots
Nanorods

nanoGold

- GnPs have been produced since ancient times
- GnPs in the art of staining glasses

The Lycurgus cup; in the reflected light it is green; and in the transmitted light it is red.
Late Roman, 4th century AD.



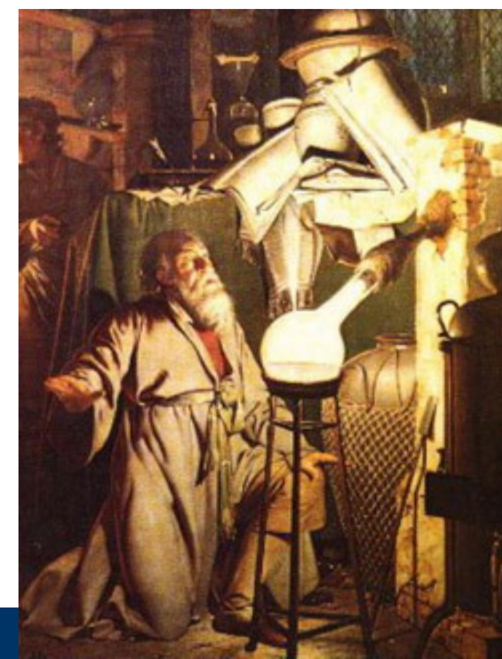
The alchemical symbol for gold.

In medicine

- Since gold does not naturally corrode, it symbolizes immortality
- Drinkable gold: “The Elixir of life”
- It was believed to produce longevity or immortality

Gold nuggets do not naturally corrode

Practitioners of alchemy aimed to produce “The Elixir of Life”



GnPs in Modern Nanotech

- Excellent physical and chemical properties:
  - Simple synthesis
  - High stability
  - Controllable size
  - Narrow size distribution
  - Excellent biocompatibility
  - Optical properties in the visible and the infrared region
  - Controllable surface chemical properties
  - …

Prophylaxis

Diagnostics

Chemical detection

Imaging

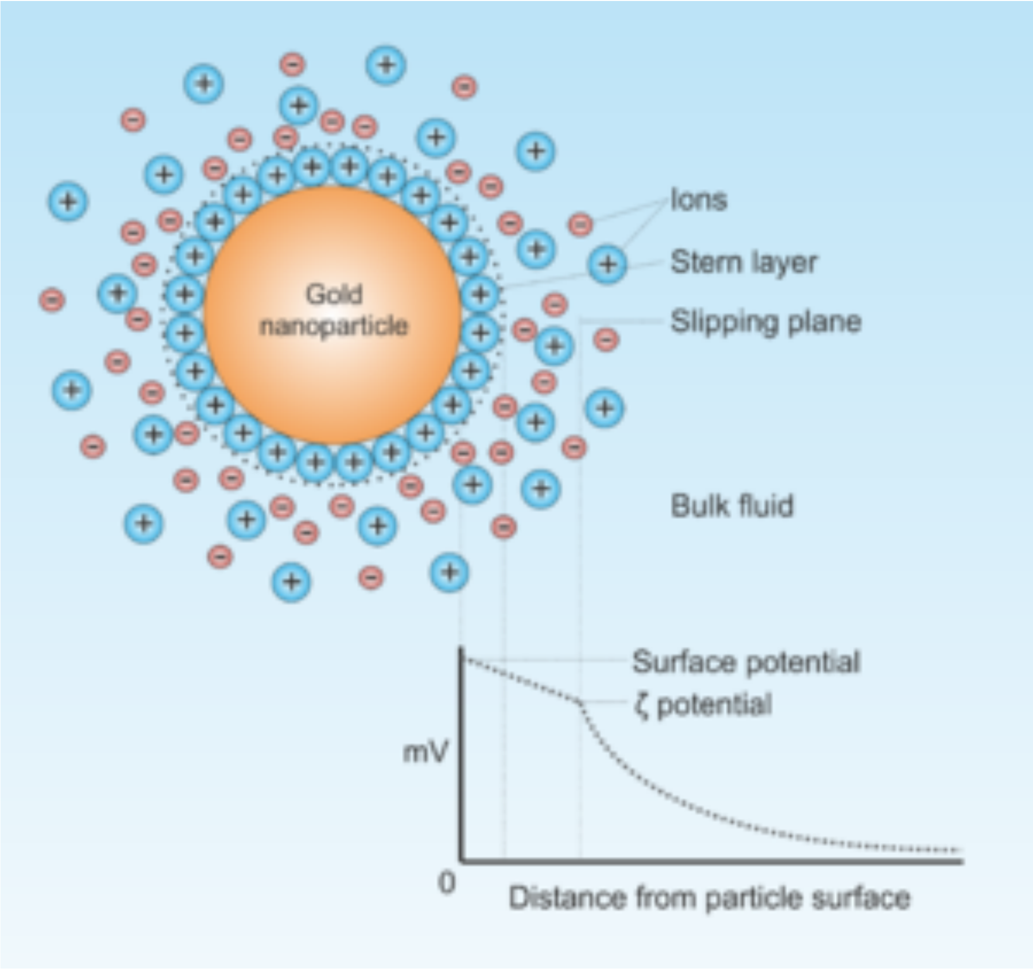
Hygiene

Therapy

- Control of surface area/mass
- Material: Au
  - 1 x 1 x 1 cm cube
  - V = 1 cm^3
  - Mass = 19.3 g
  - Surface area = **6 cm^2**

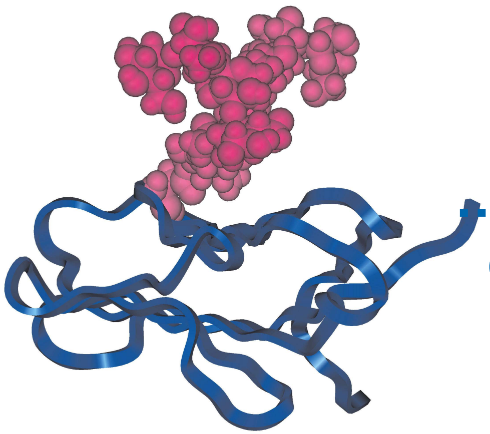
- 10x10x10 nm nanocubes
  - No. of nanocubes = 1 x 10^{18}
  - V = 1000 nm^3
  - Surface area per nanocube = 600 nm^2
  - Total surface area= 6 x 10^{20} nm^2

= **6 000 000 cm^2**

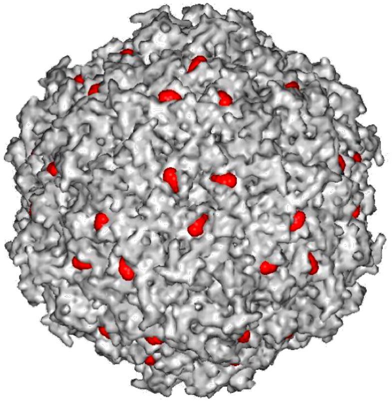

Gold nanoparticle
Ions
Stern layer
Slipping plane
Bulk fluid
Surface potential
ζ potential
mV
0
Distance from particle surface

Nature builds devices from nanoscale components

Biopolymers…..

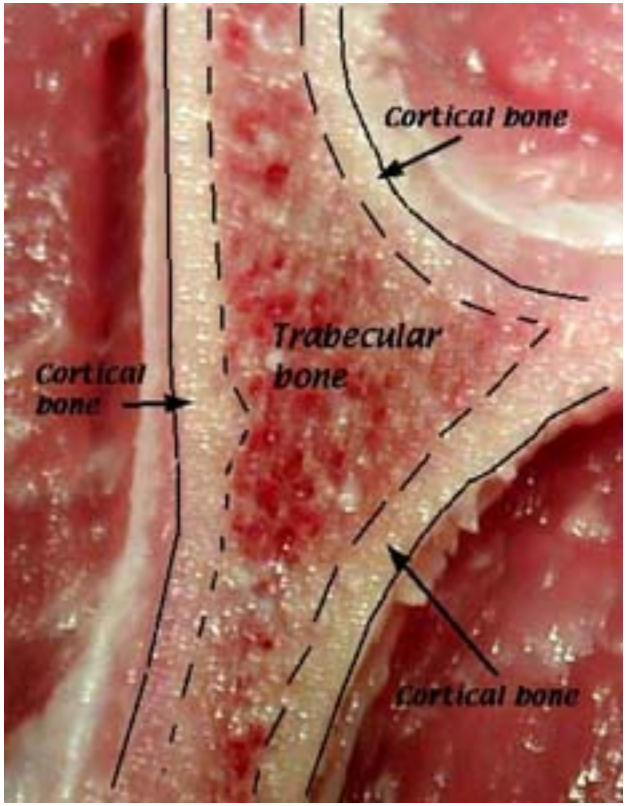


…assemble into complexes….

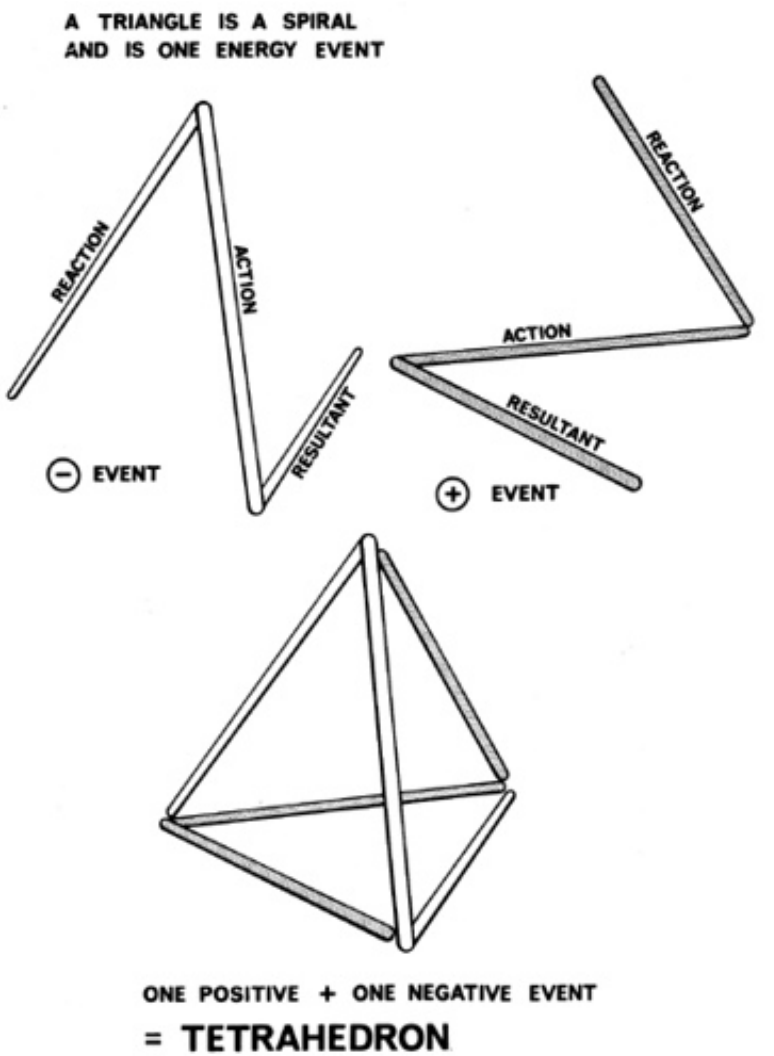


…from which complex machines are built.

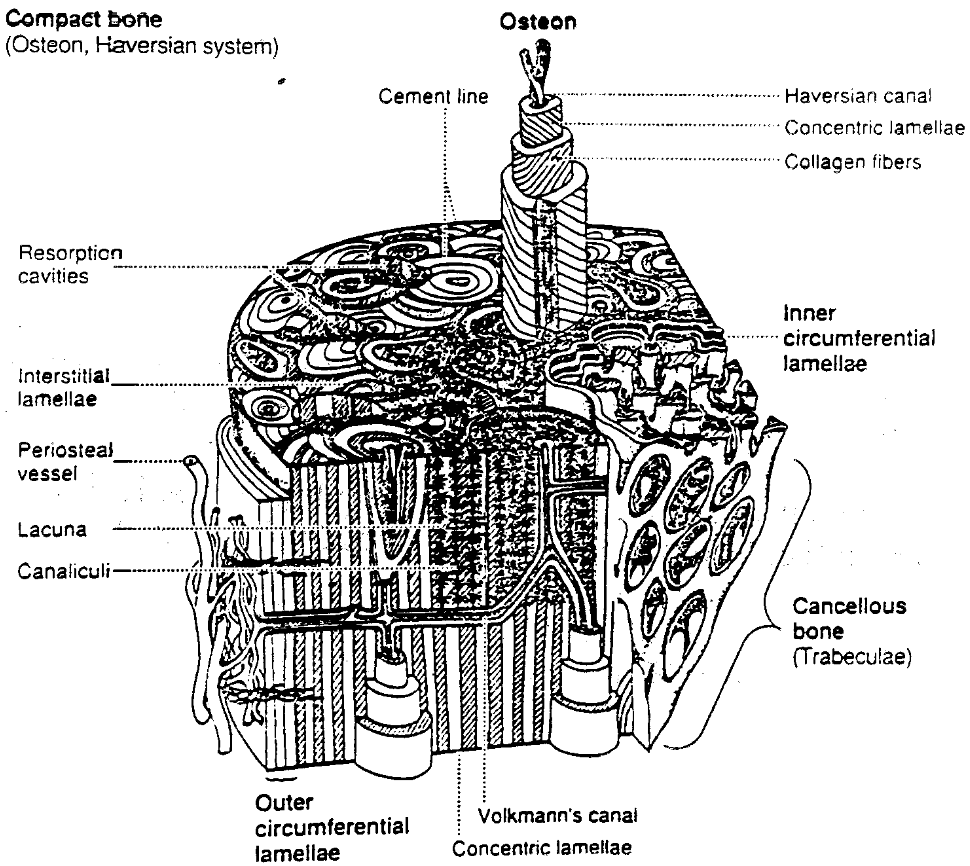
Advanced natural materials:

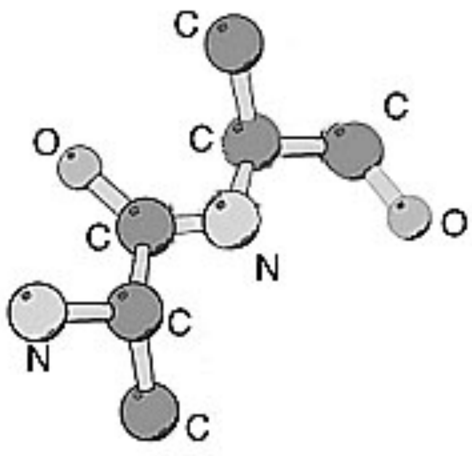


Synergetic materials:



Bone: pure synergetics




C
C
C
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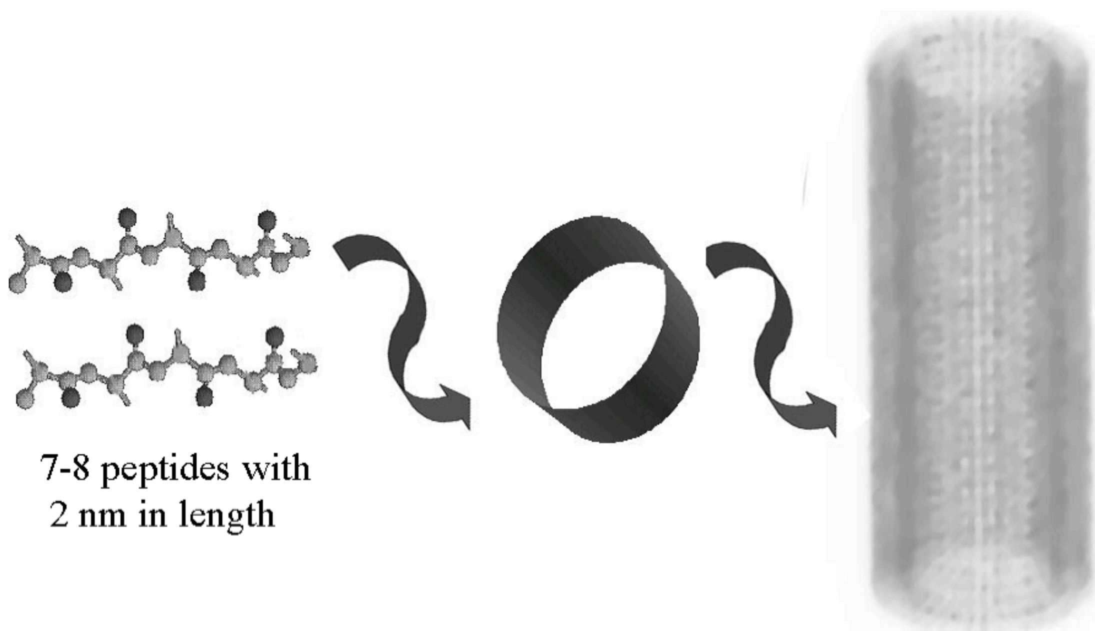
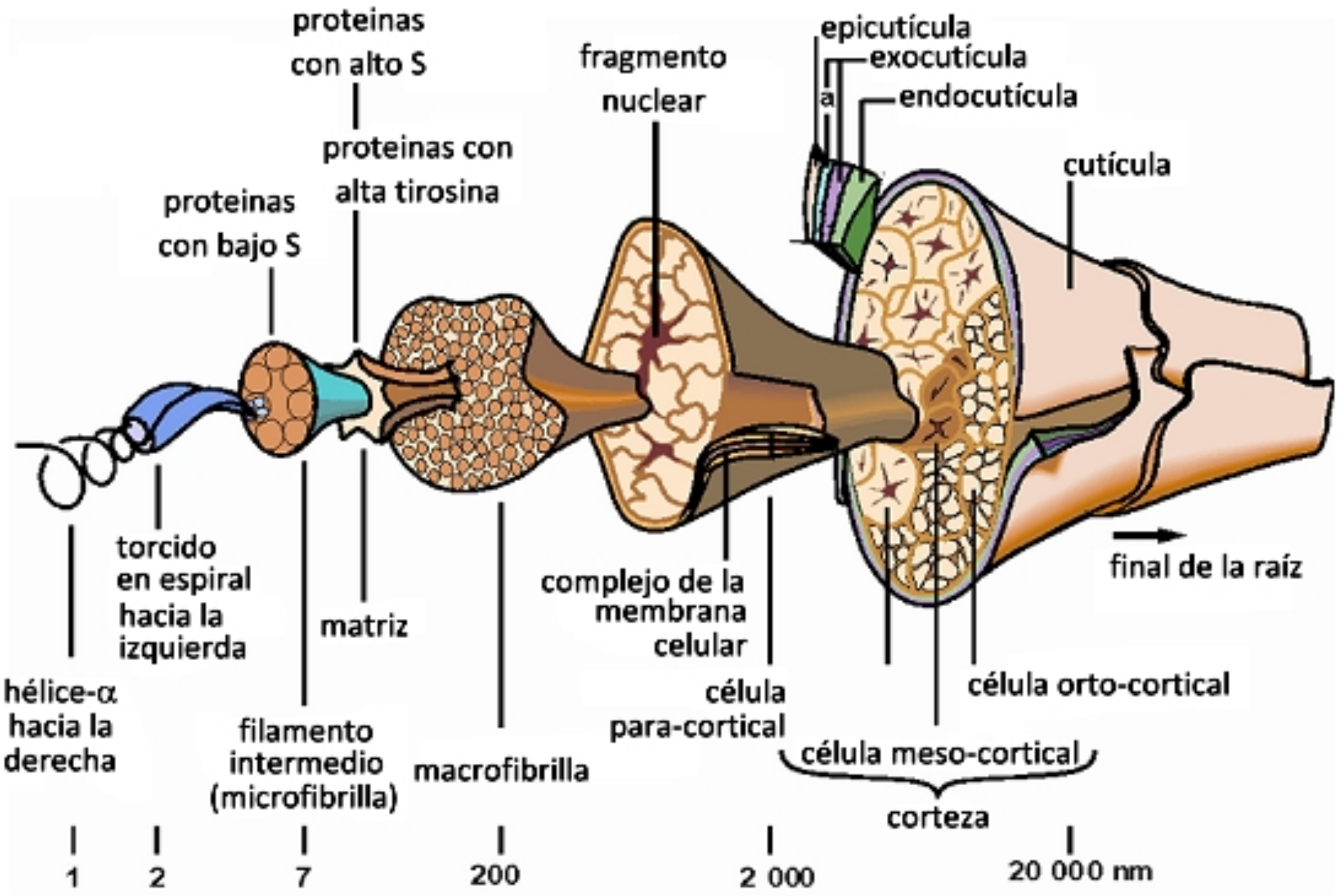

7-8 peptides with
2 nm in length

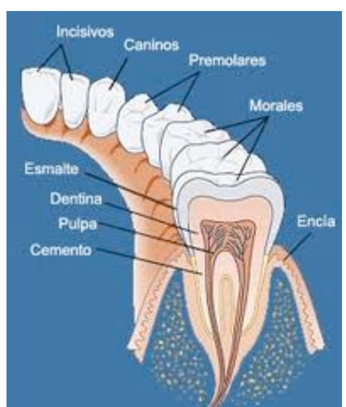
Little engineering marvels: feathers

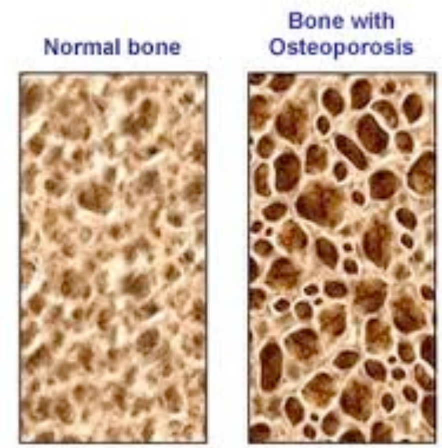


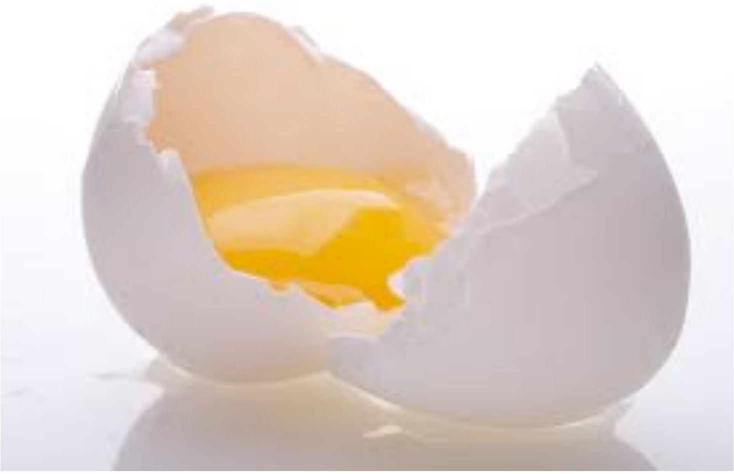
Dental materials and bone-replacements

Bone:
Synergetic combination of Hydroxyapatite (HAp) and collagen

$Ca_5(PO_4)_3(OH)$

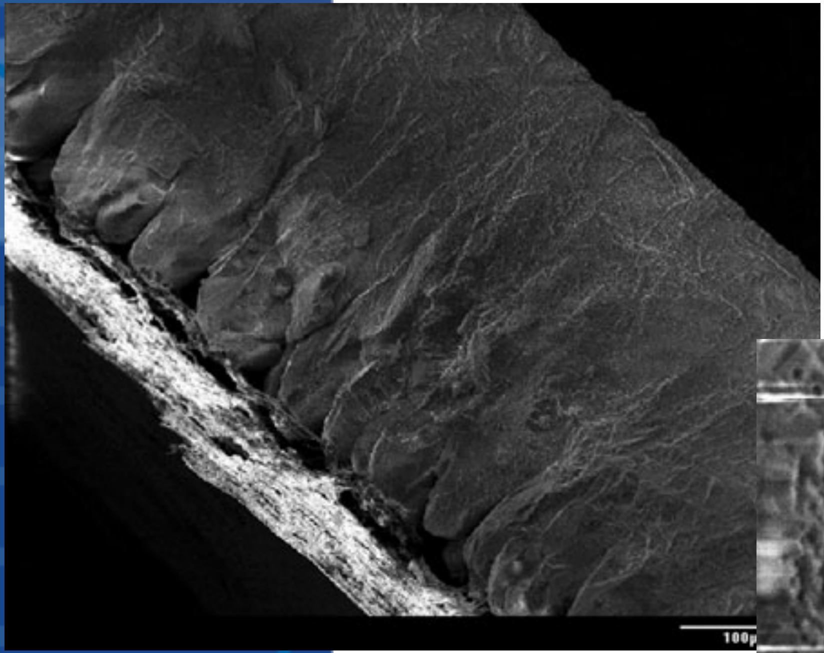


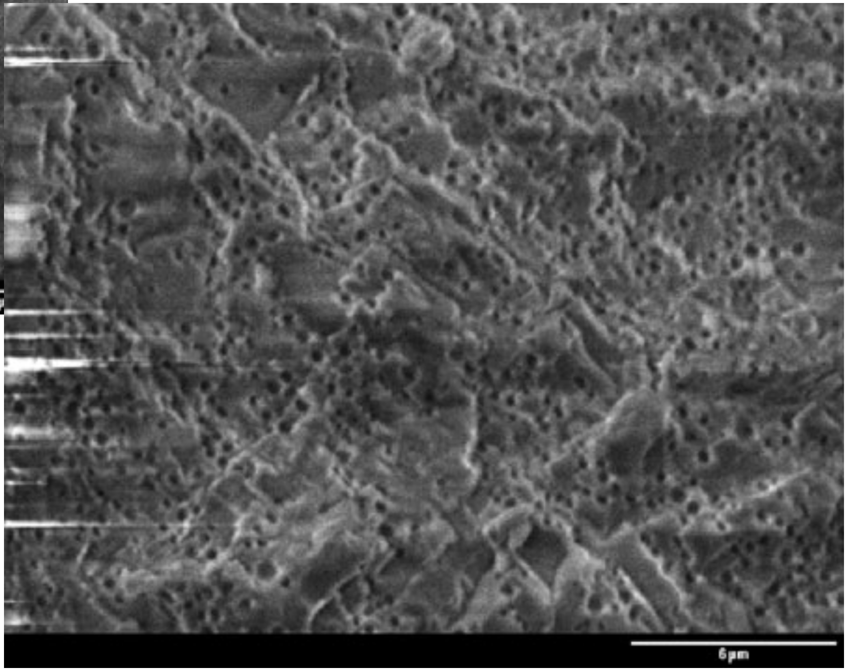




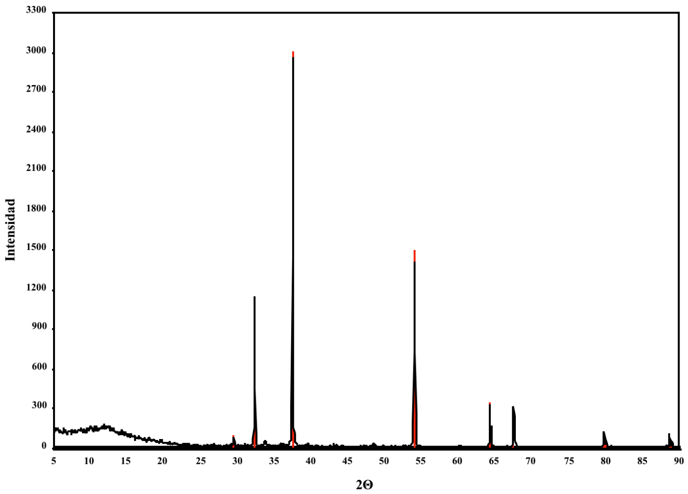
In the USA,
550,000,000
dozens of eggs
were produced
monthly
as for 2006

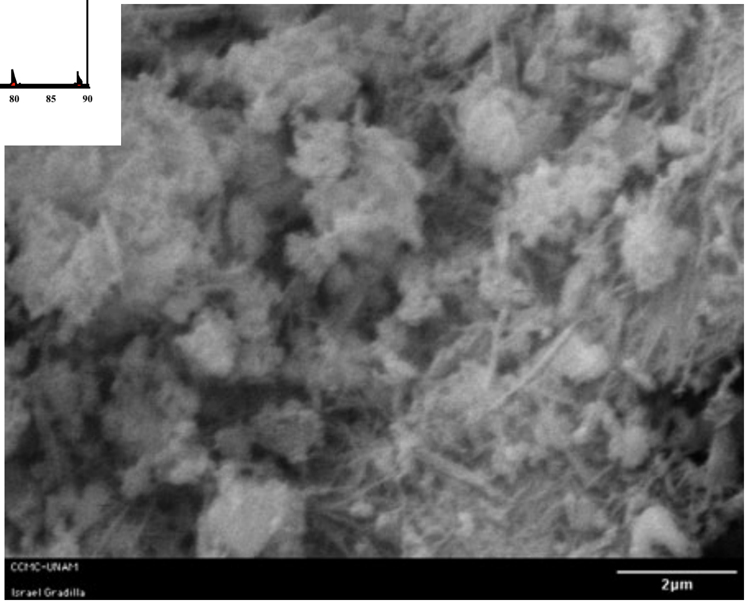
SEM of typical eggshell (Calcium carbonate)





After hydrothermal treatment (HAp)



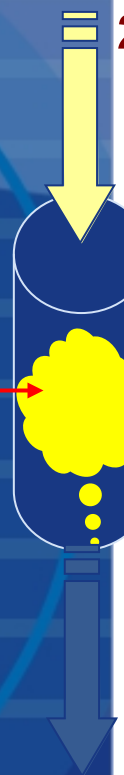


Water treatment technologies

Removal of Cr VI and Lead with nanokeratin biofiber filters

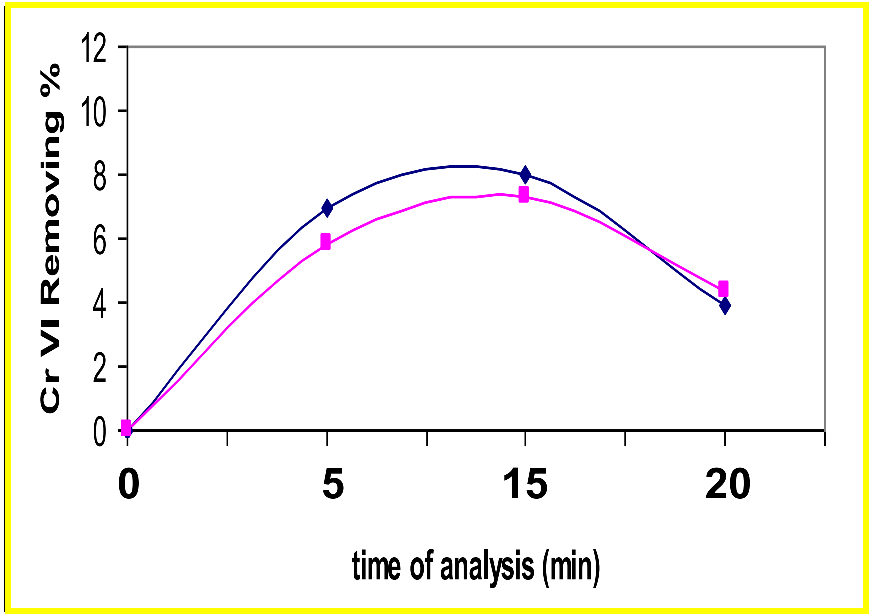
Poluted water
20 ppm Cr VI

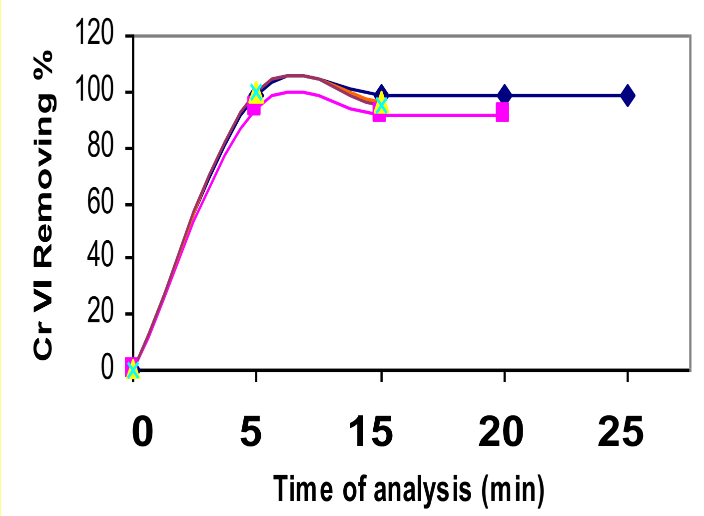
Keratin biofiber



Treated water

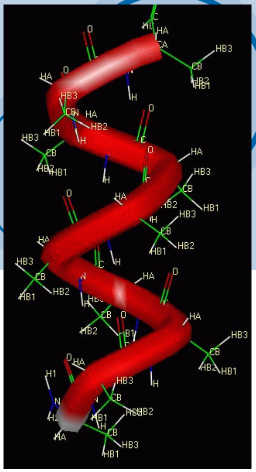
Untreated Keratin biofiber



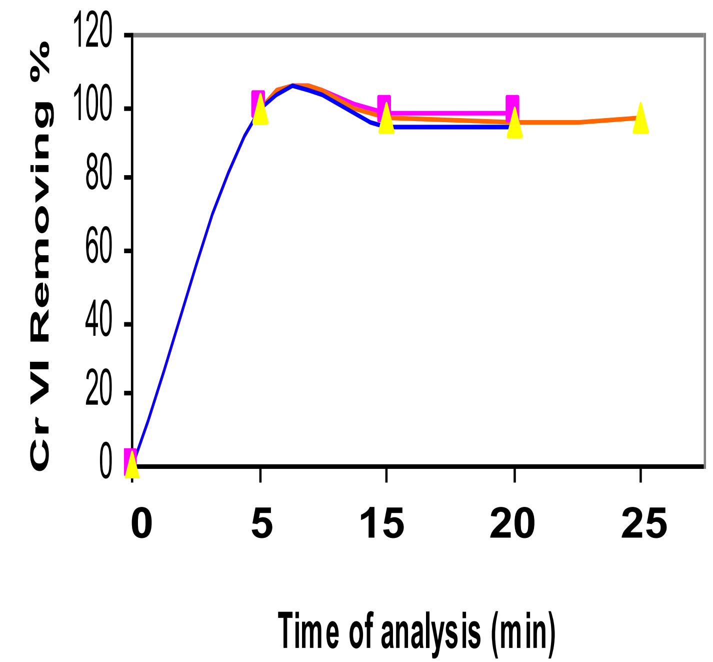


Keratin biobifer treated with Sulfuric acid (pH 3)

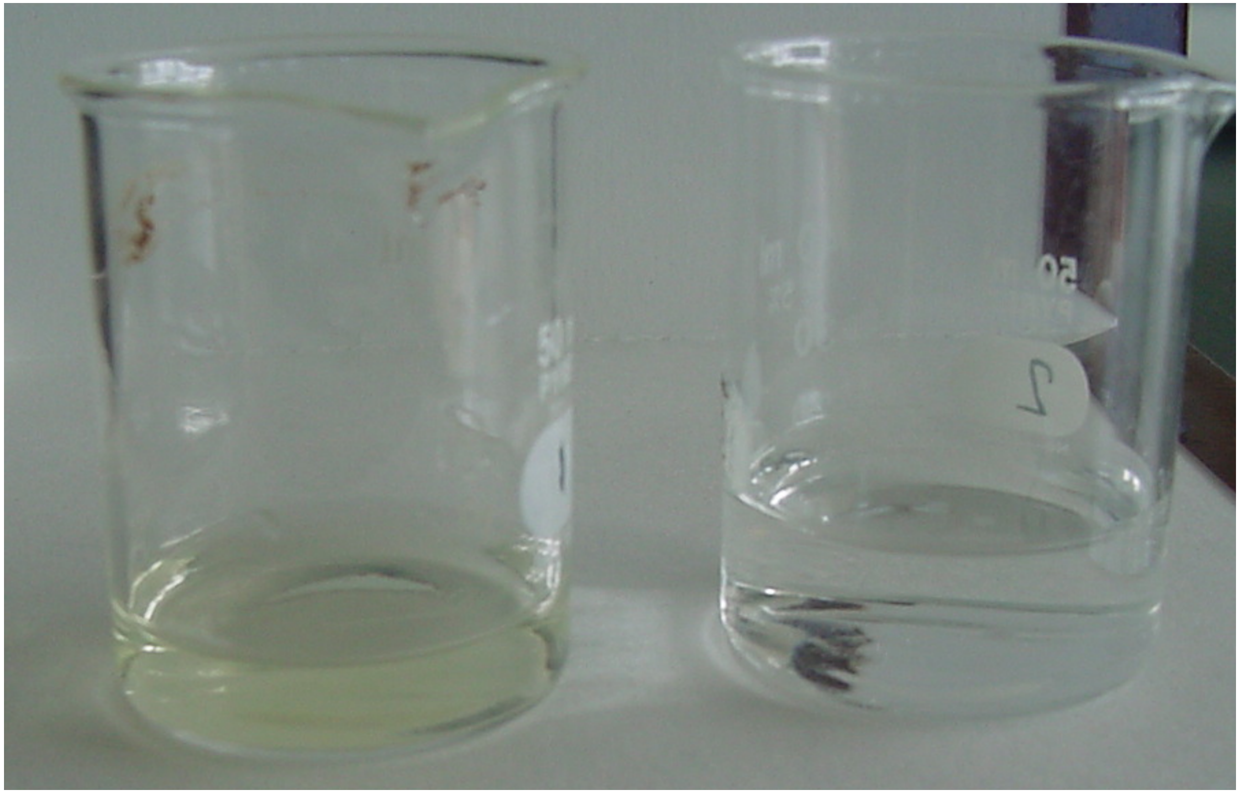
Active sulfur sites to retain metals



Keratin biobifer treated with Sulfuric acid (pH 6)

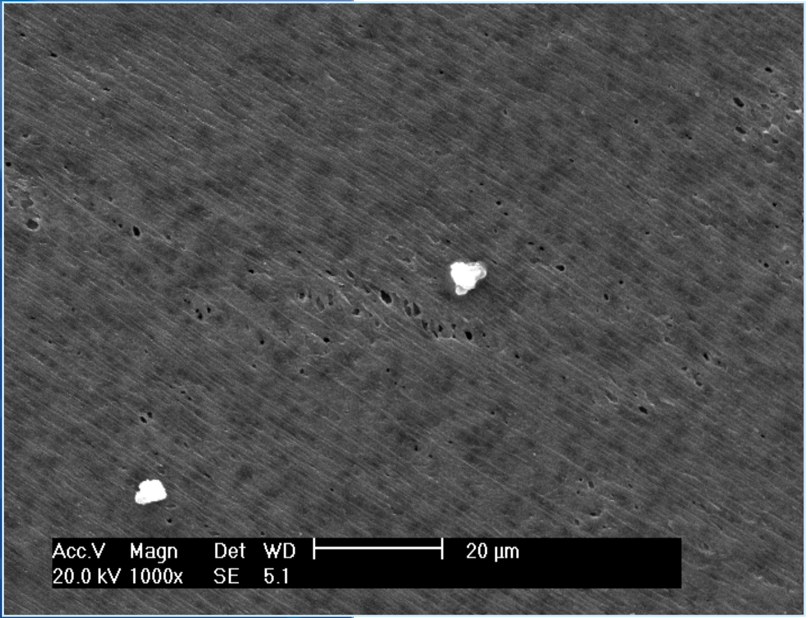


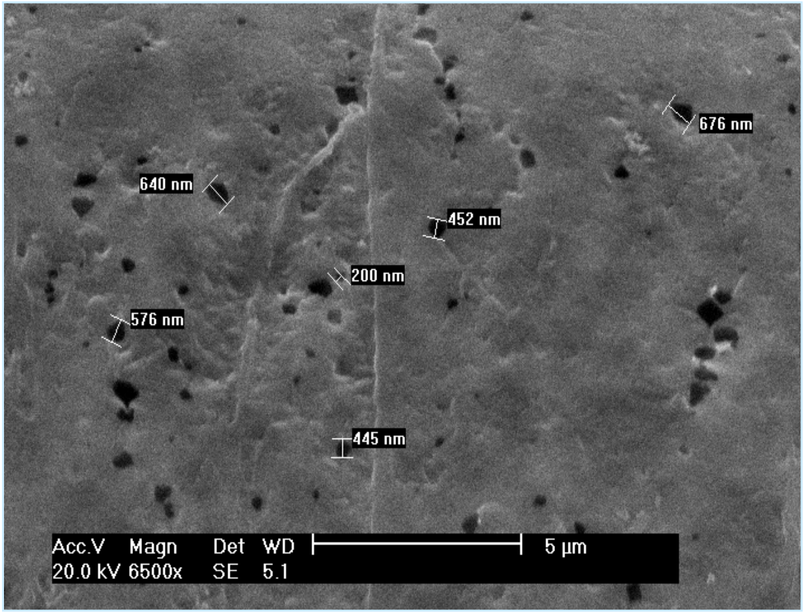
Water with 20 ppm of Cr VI



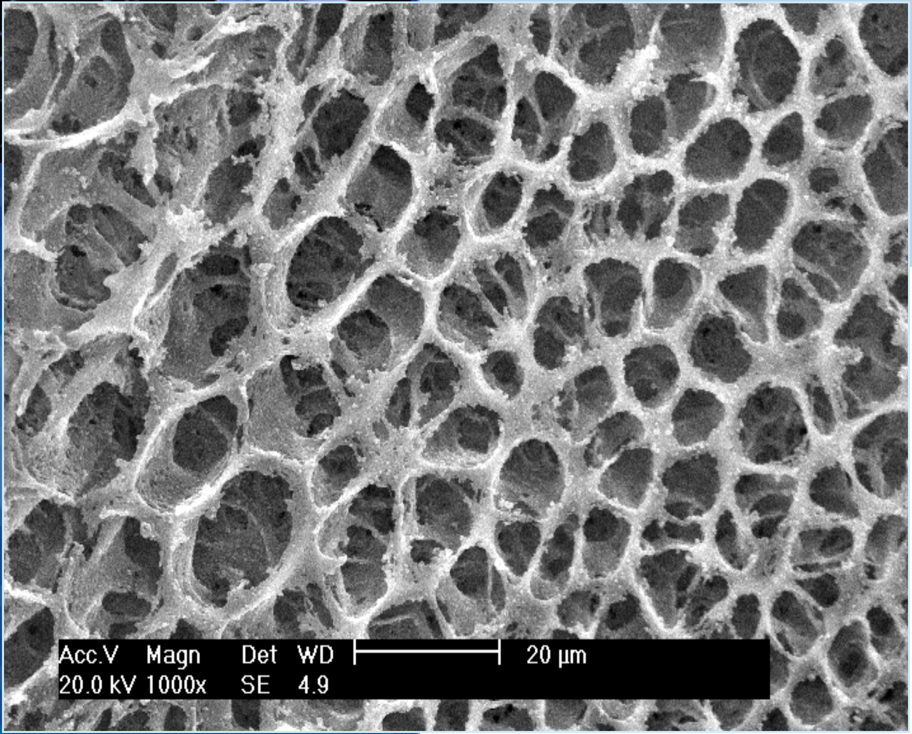
Water after treatment with modified keratin biofiber

Removing Cr VI with nylon – keratin membranes

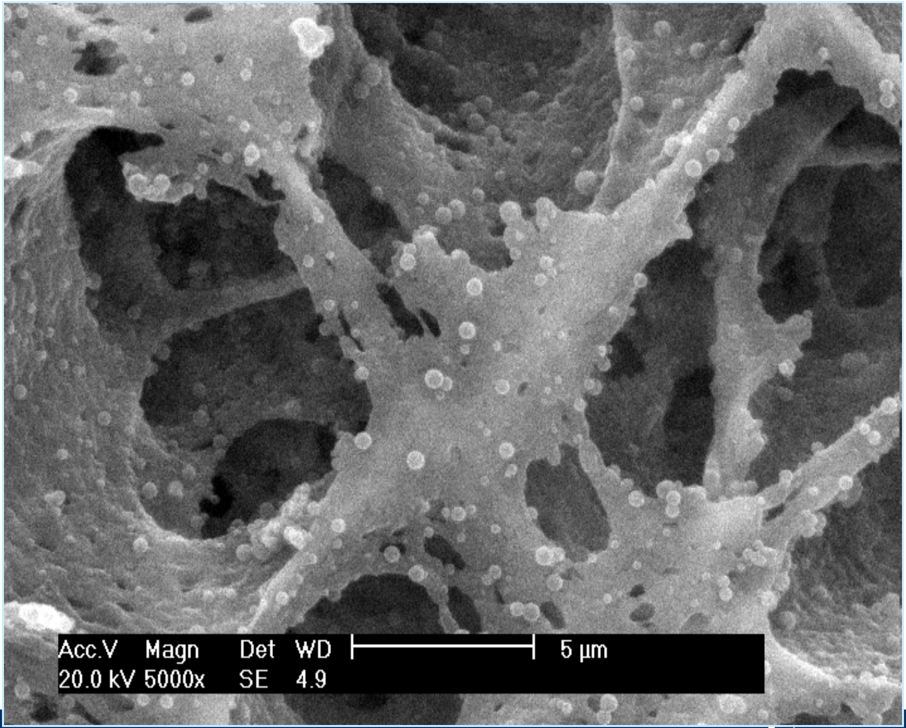




Nylon membranes without keratin

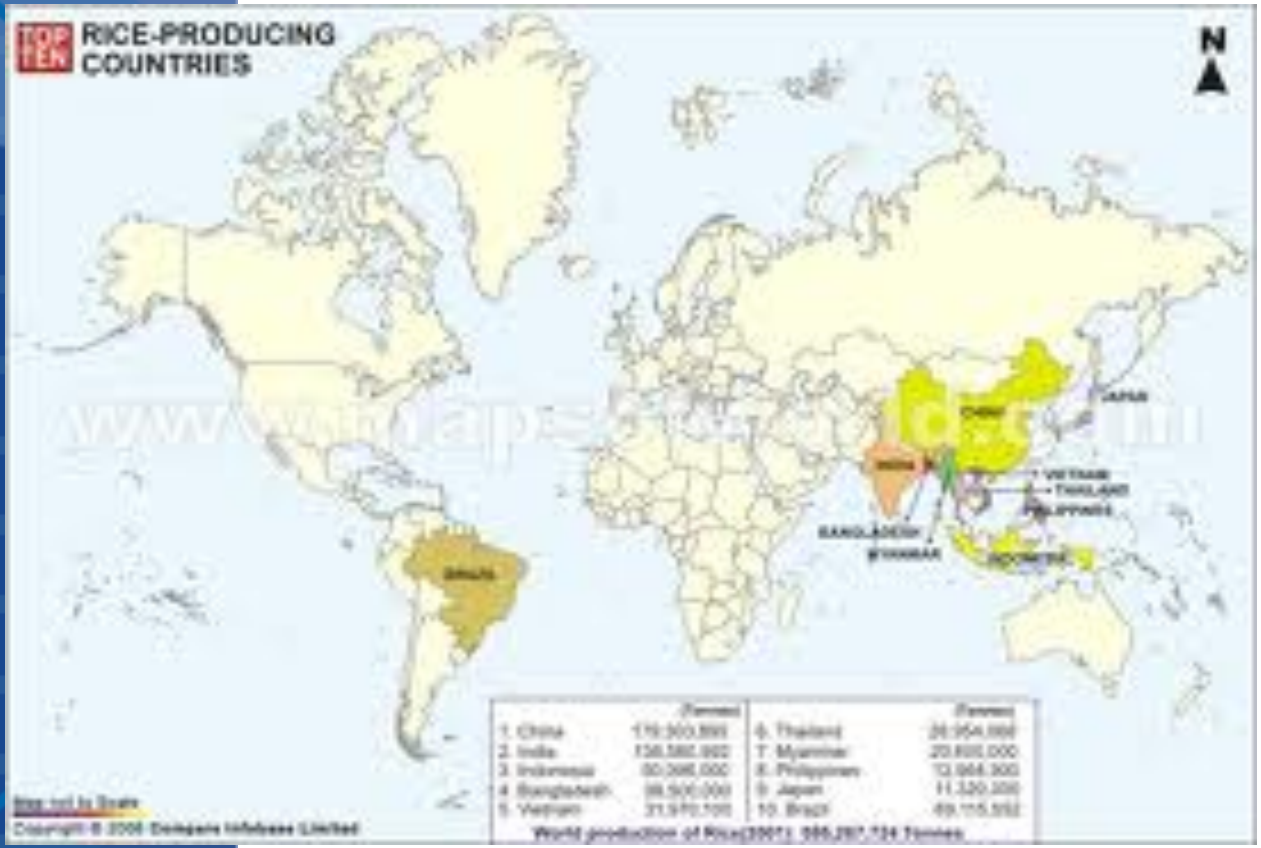


Nylon membranes with keratin Micro and nano spheres

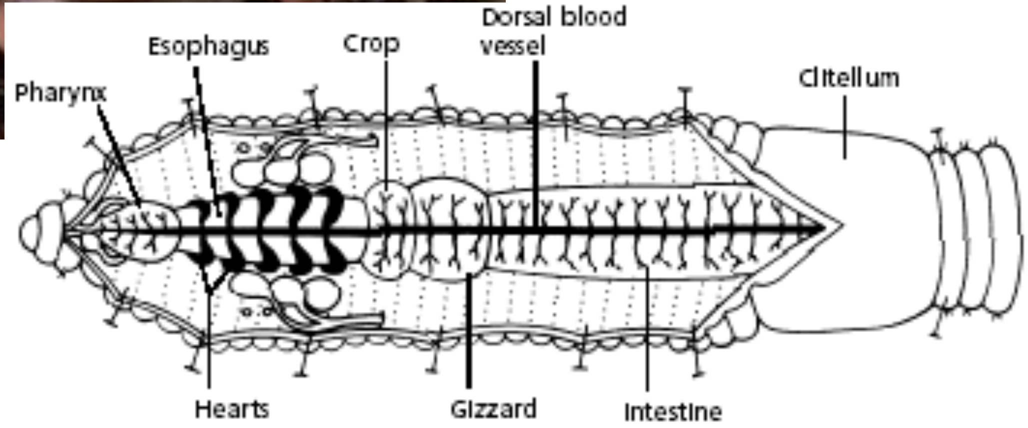


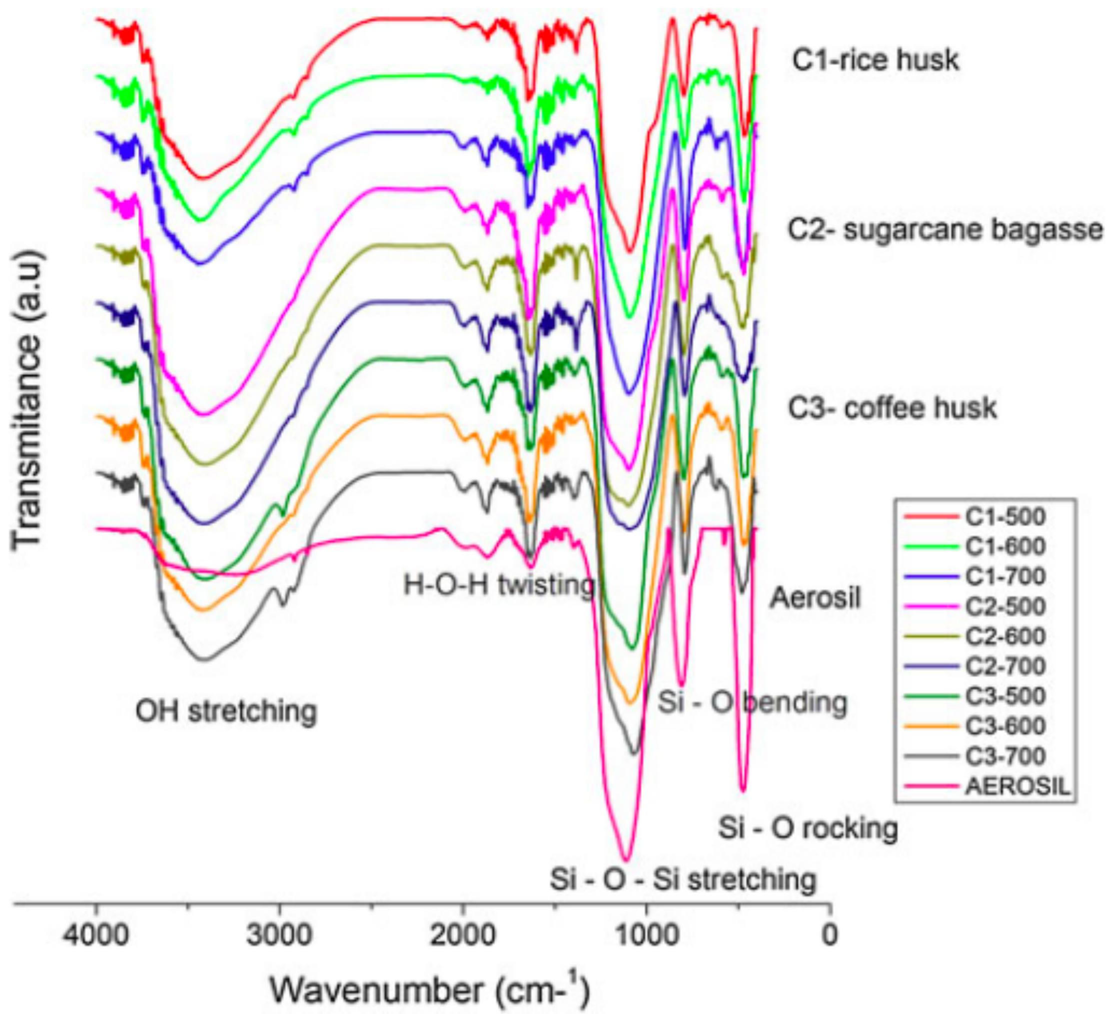
Bioprocessing of nanoparticles

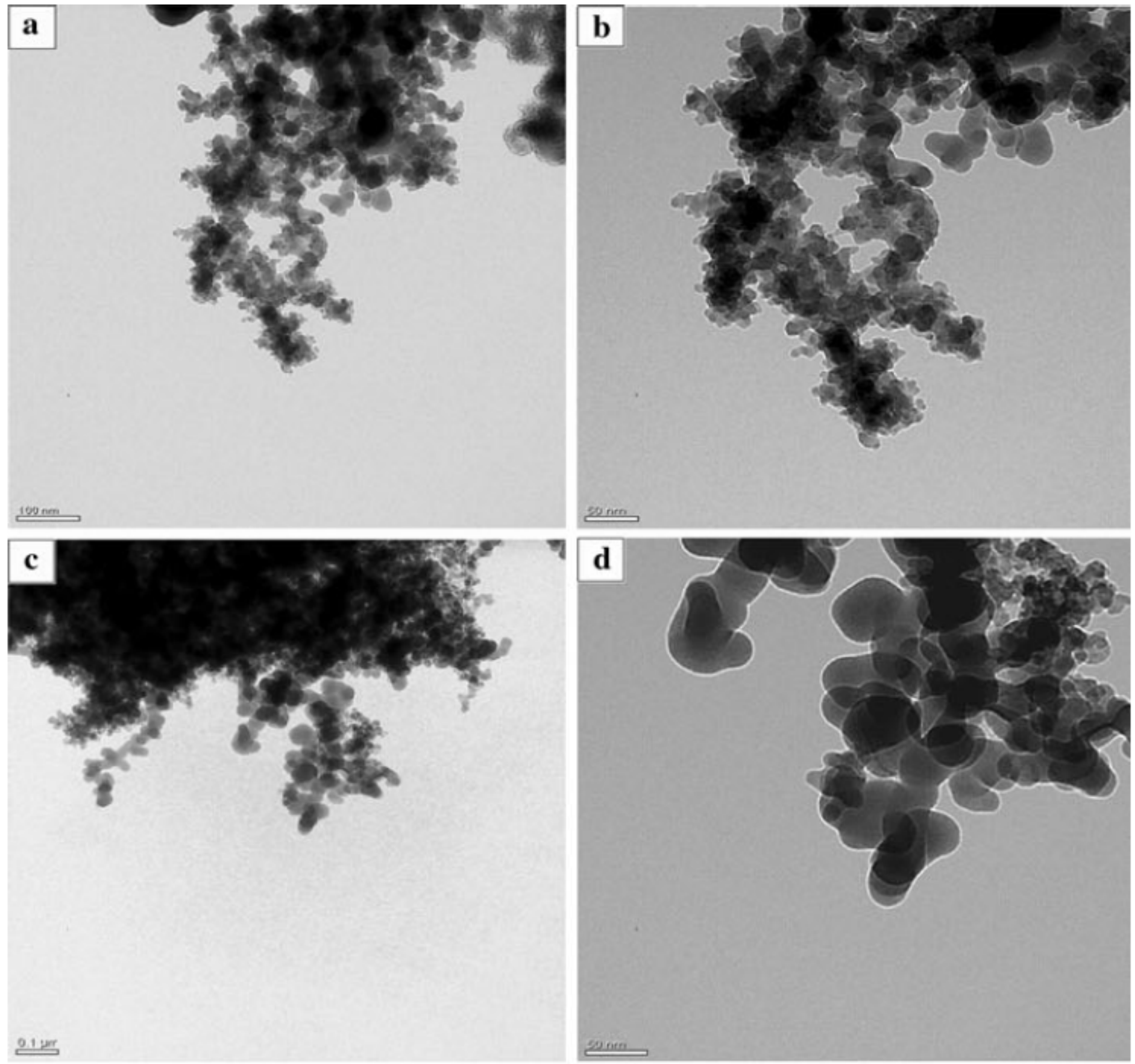
Rice husk: an environmental challenge



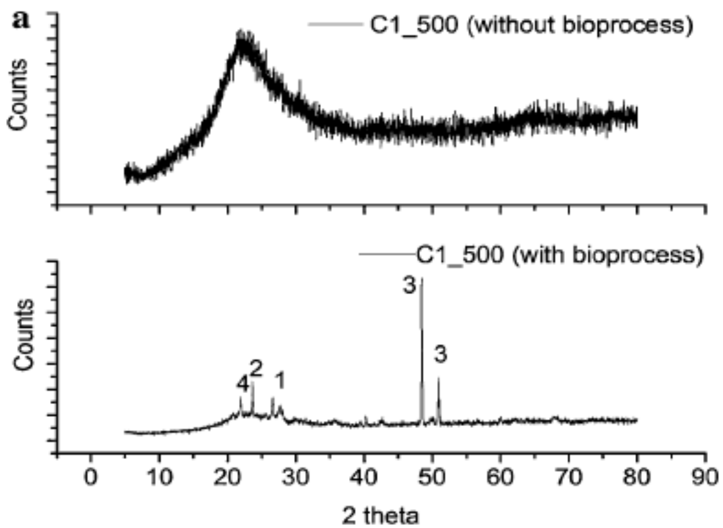
Annelids: over 12,000 species



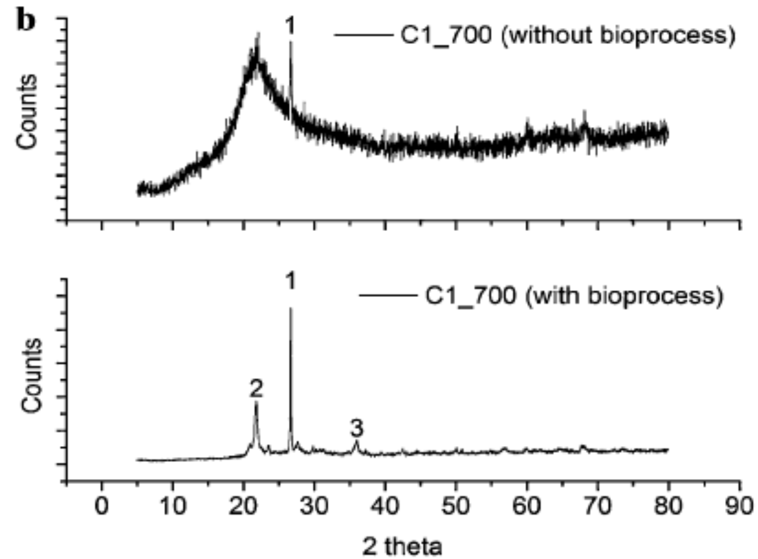

C1-rice husk
C2- sugarcane bagasse
C3- coffee husk
Aerosil
H-O-H twisting
OH stretching
Si - O bending
Si - O rocking
Si - O - Si stretching
C1-500
C1-600
C1-700
C2-500
C2-600
C2-700
C3-500
C3-600
C3-700
AEROSIL
Transmitance (a.u)
4000
3000
2000
1000
0
Wavenumber (cm-1)



a
b
c
d
100 nm
50 nm
0.1 μm
50 nm



1. Hexagonal quartz α (1,0,1)
2. Hexagonal erionite (0,0,4)
3. Hexagonal trydimite (primitive) (4,1,7) (1,1,43)
4. Triclinic albite (-2,0,1)



1. Hexagonal quartz α (1,0,1)
2. Triclinic albite (0,0,4)
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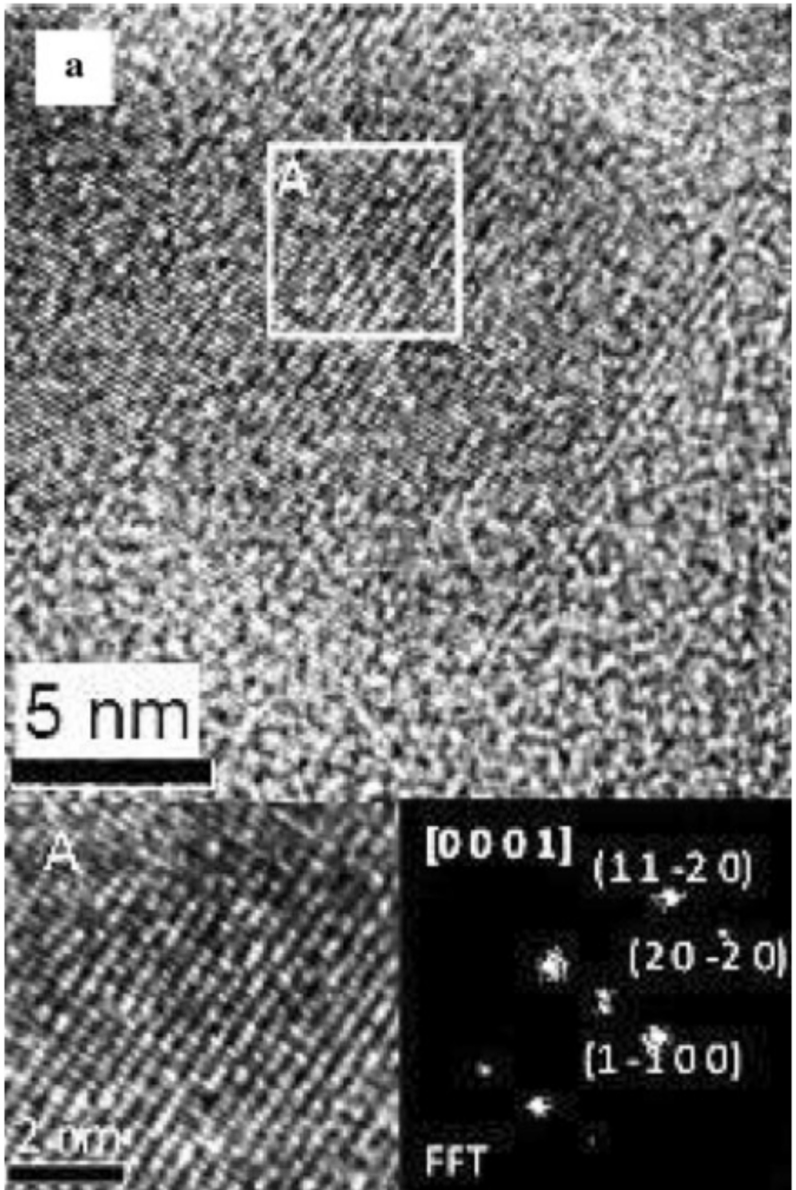
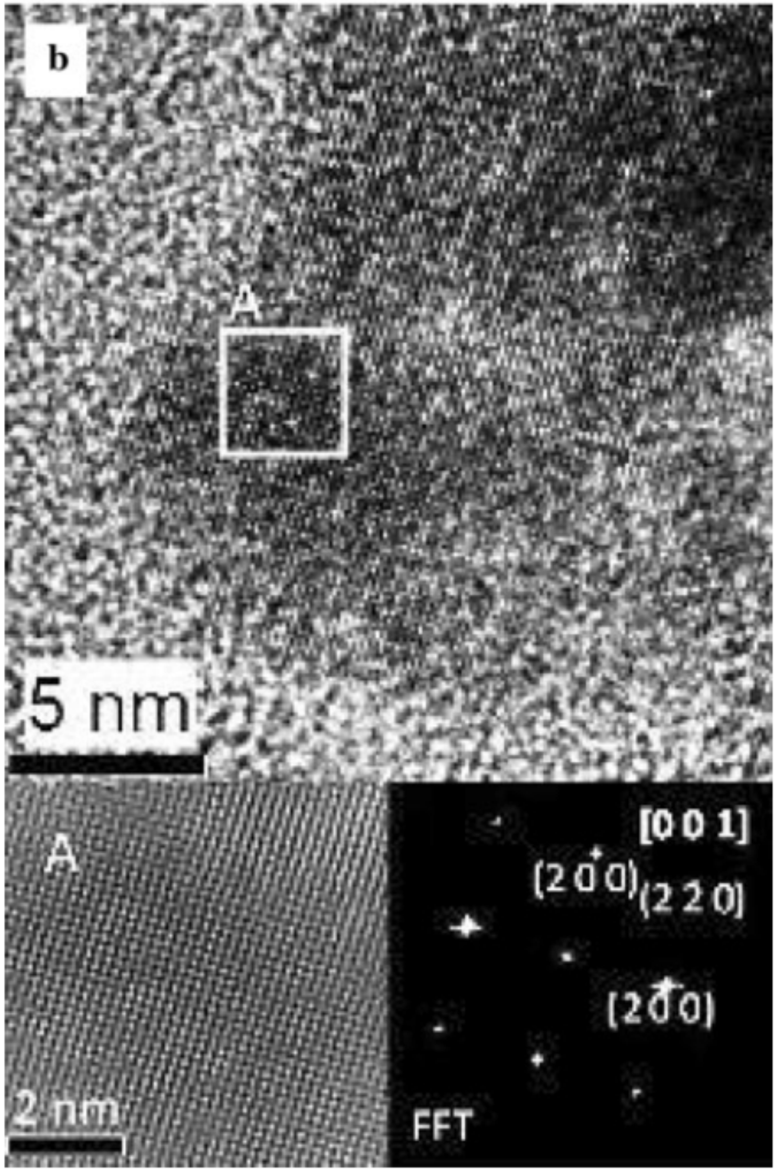
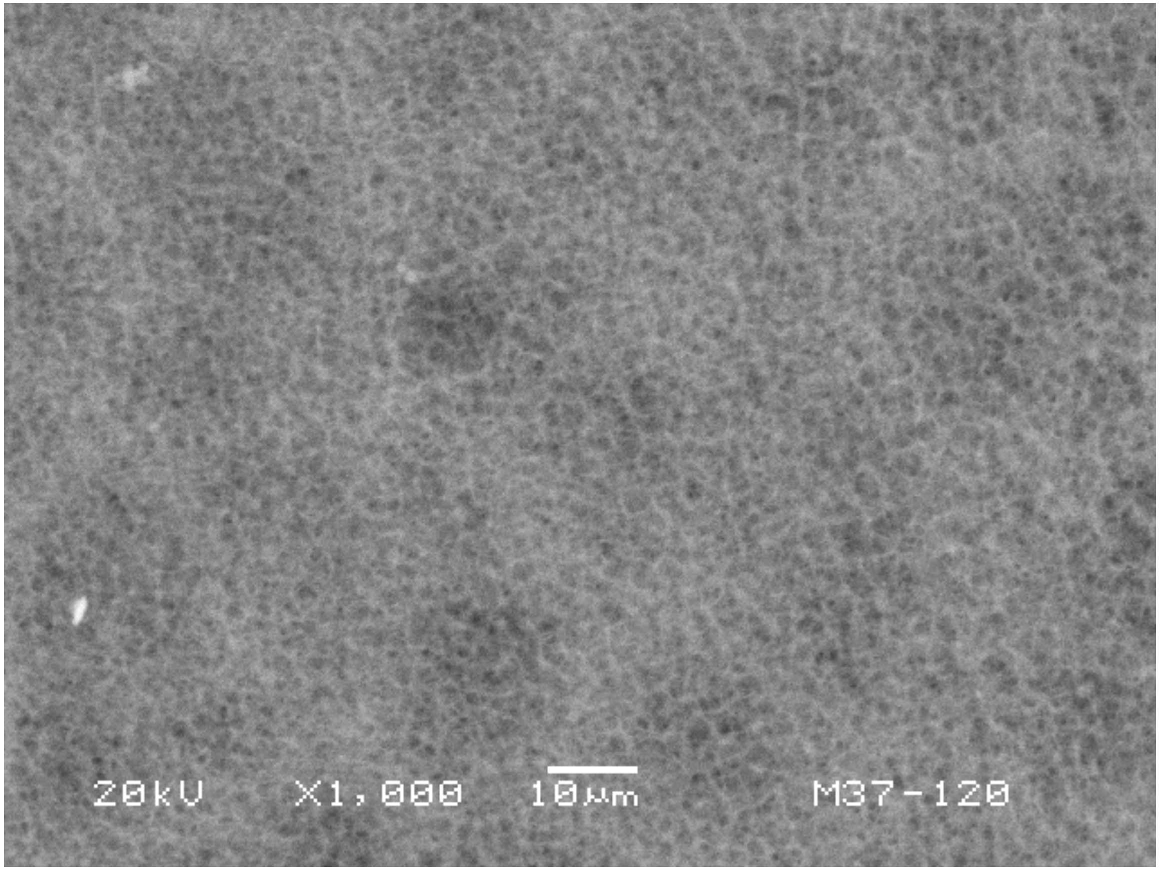
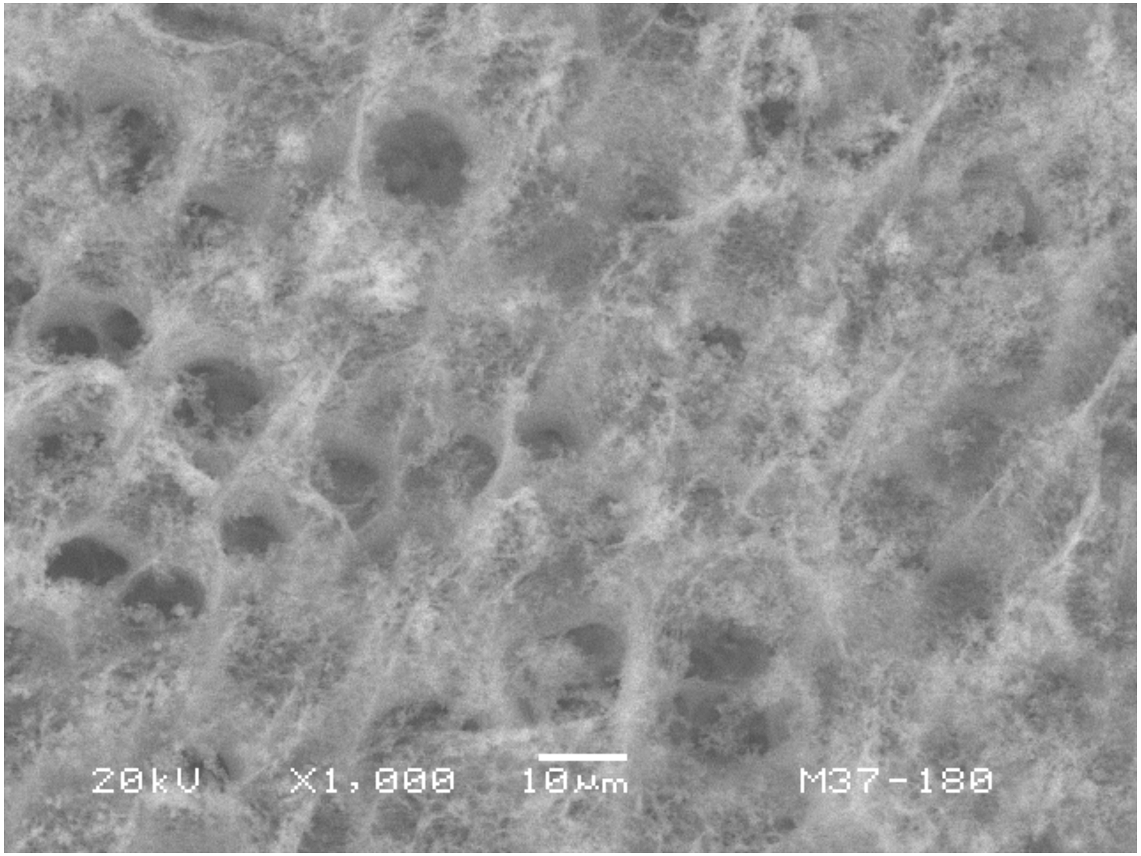

a
A
5 nm
A
2 nm
[0 0 0 1]
(1 1 -2 0)
(2 0 -2 0)
(1 -1 0 0)
FFT

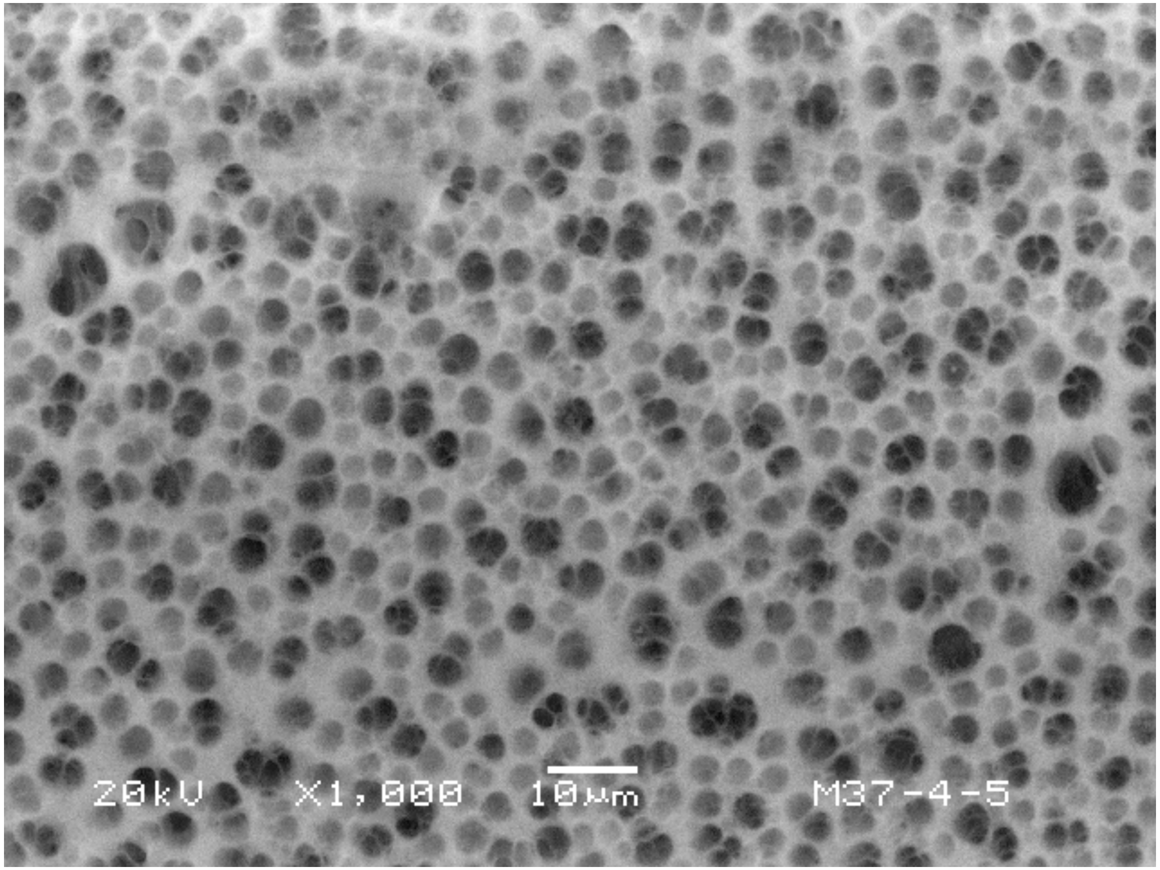

b
A
5 nm
A
2 nm
[0 0 1]
(2 0 0)
(2 2 0)
(2 0 0)
FFT

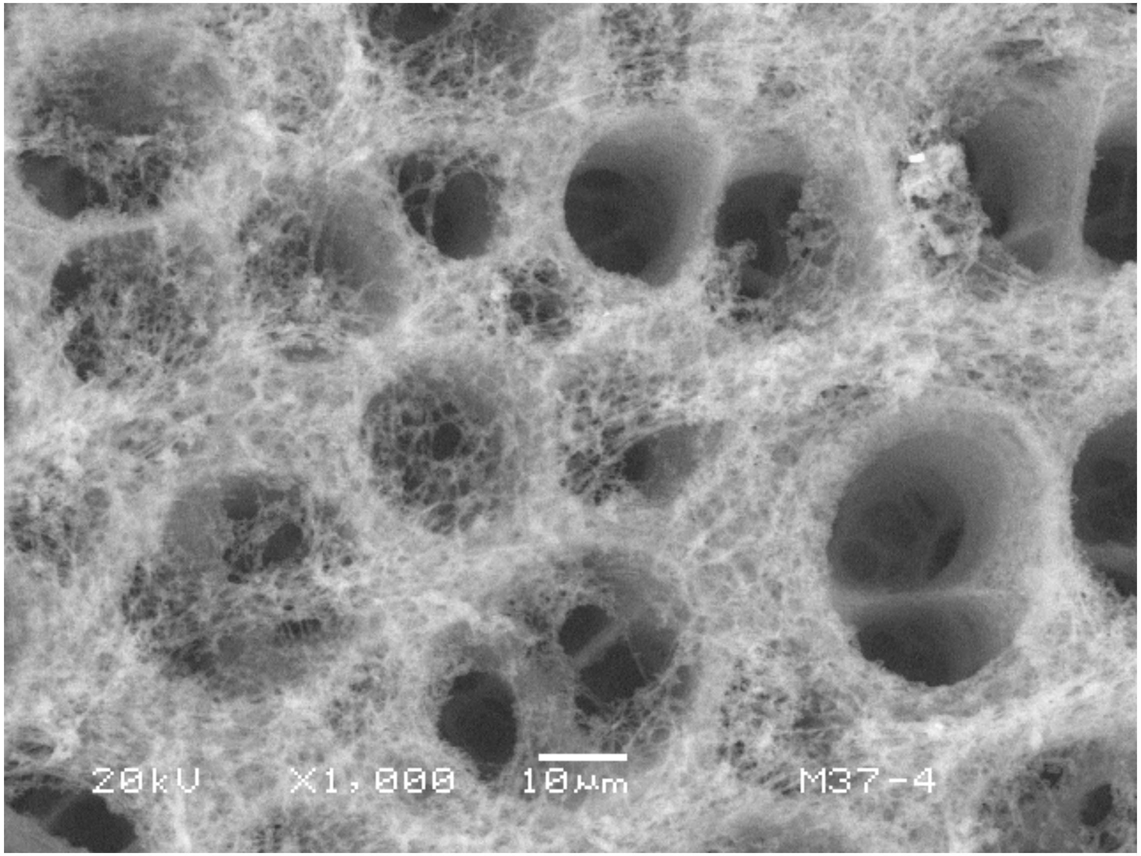
Intelligent materials

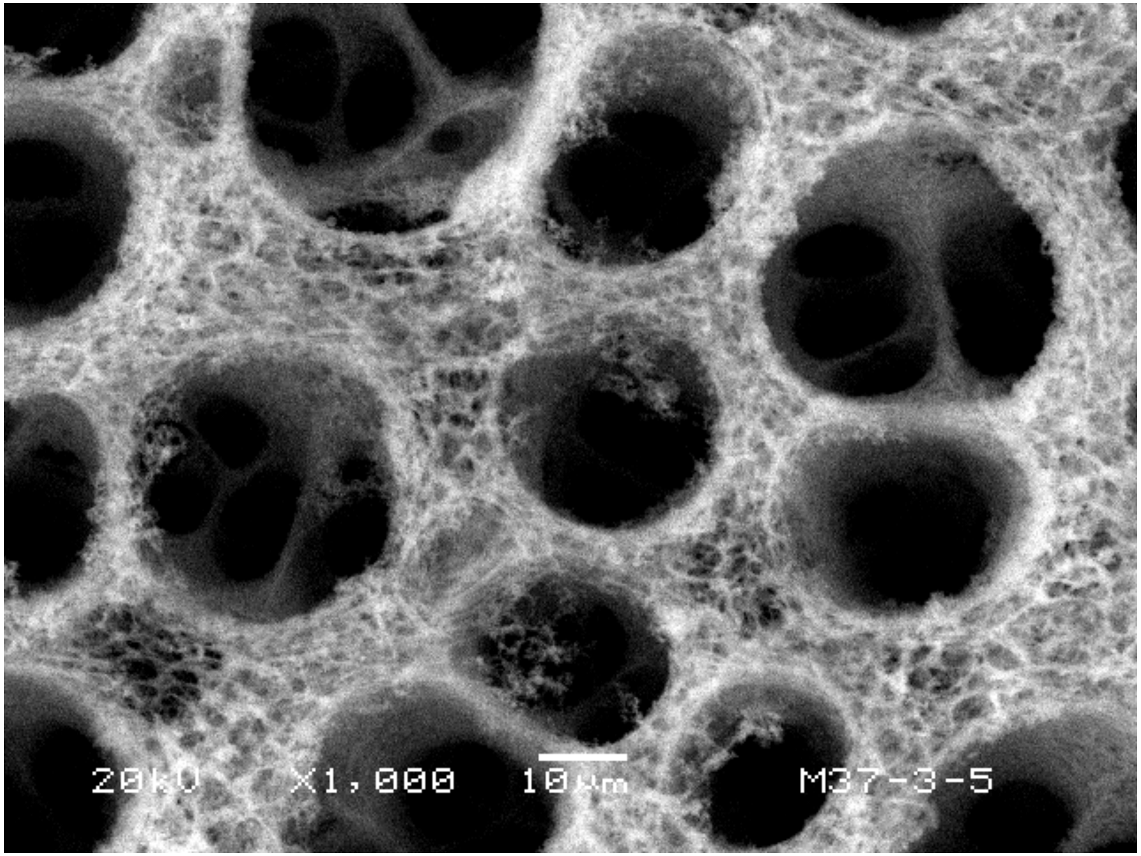
Smart membranes

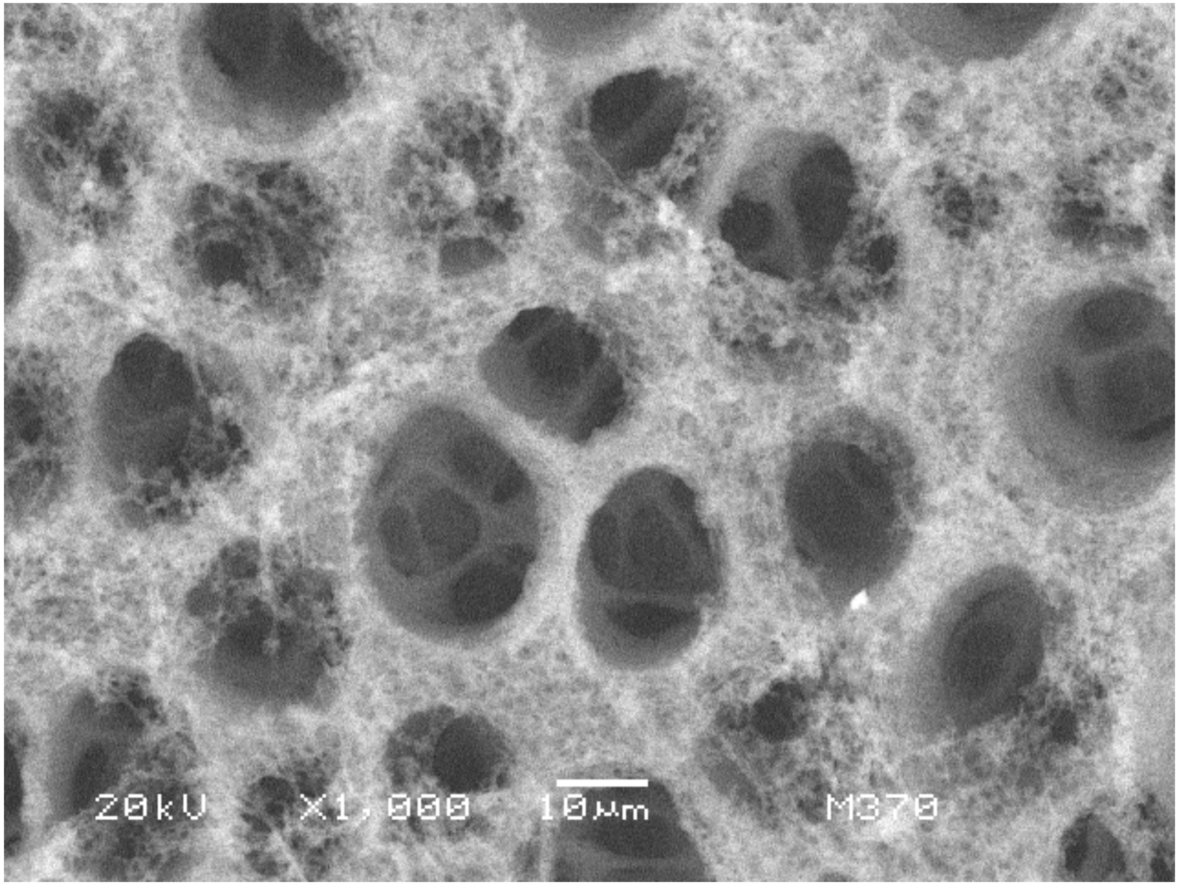


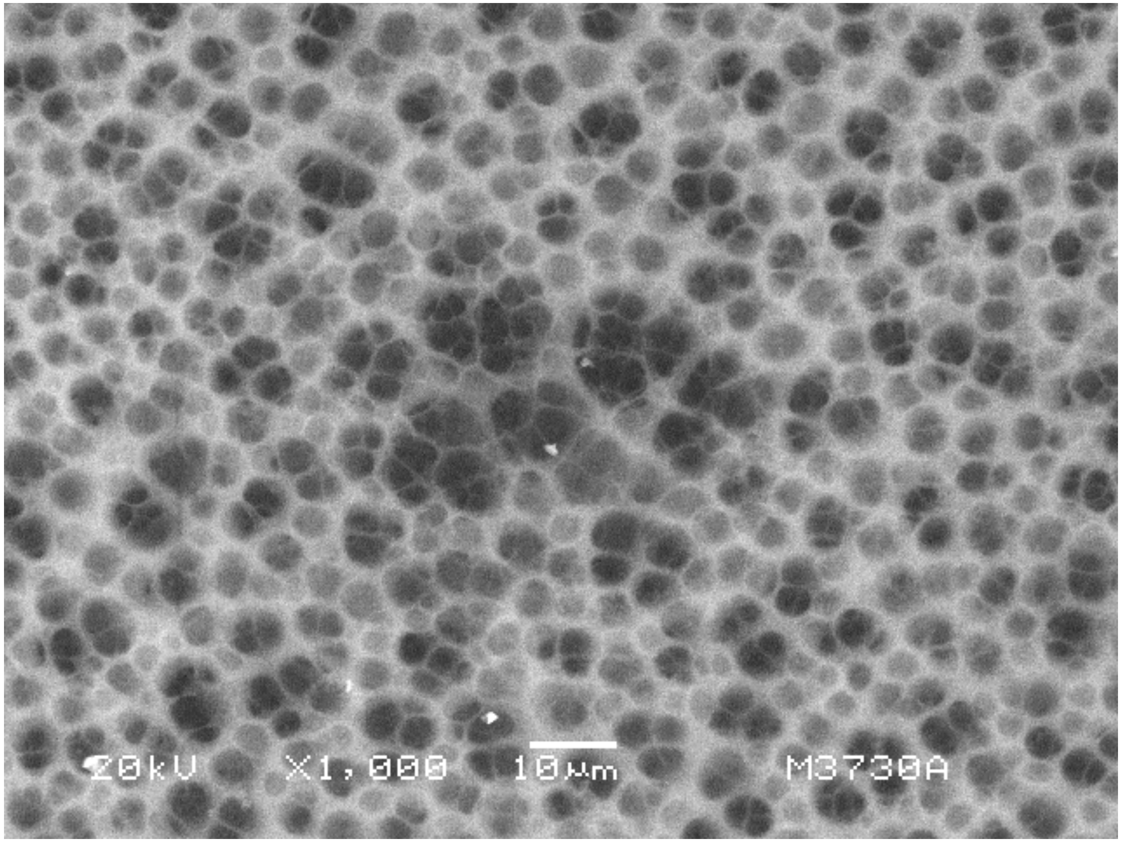

20kV X1,000 10µm M37-180

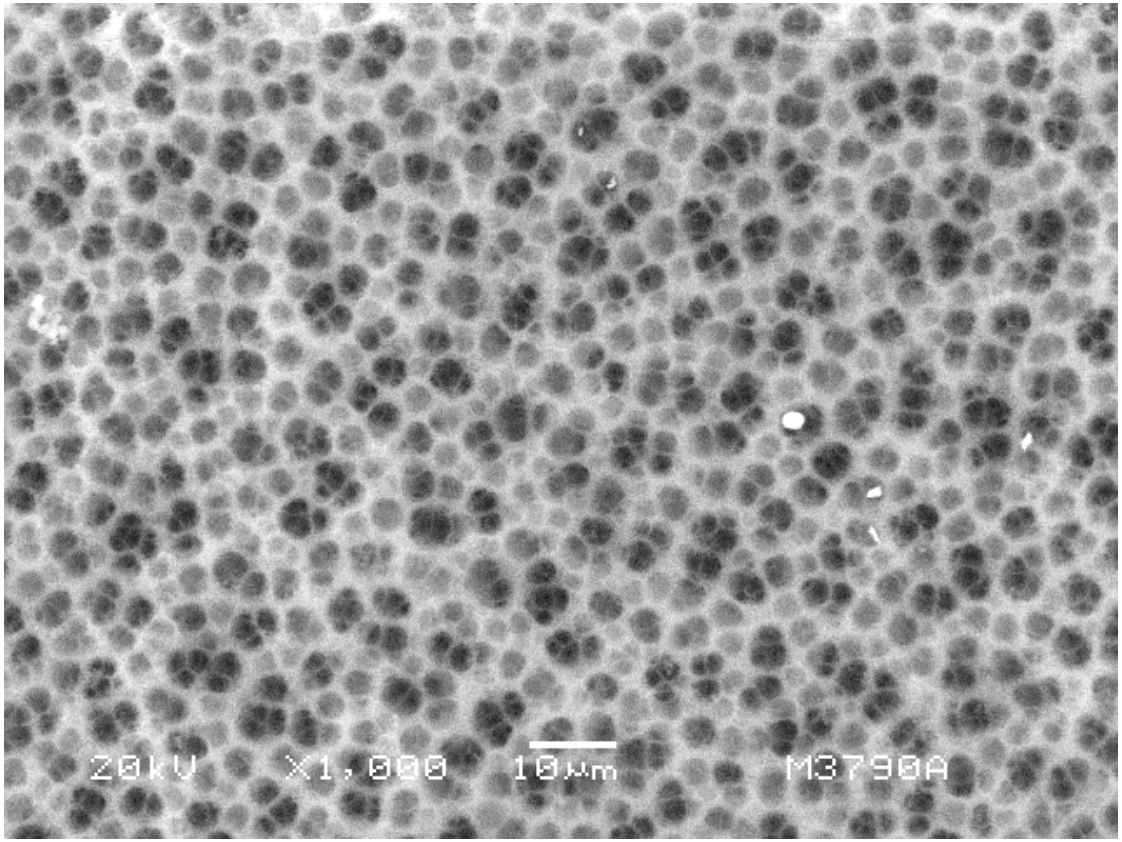

20kV X1,000 10µm M37-4-5


20kV
X1,000
10µm
M37-4


20kV X1,000 10µm M37-3-5


20kV X1,000 10µm M370


20kV X1,000 10μm M3730A


20kV X1,000 10µm M3790A

$$t = 0$$

$$\Phi_x(t = 0) = 0$$

$$\Phi_y(t = 0) = \Phi_o$$

$$t > 0$$

$$\Phi_x(t) = \Phi_o\left(\frac{y - y_{min}}{y}\right)$$

$$\Phi_y(t) = \Phi_o\left(\frac{y_{min}}{y}\right)$$

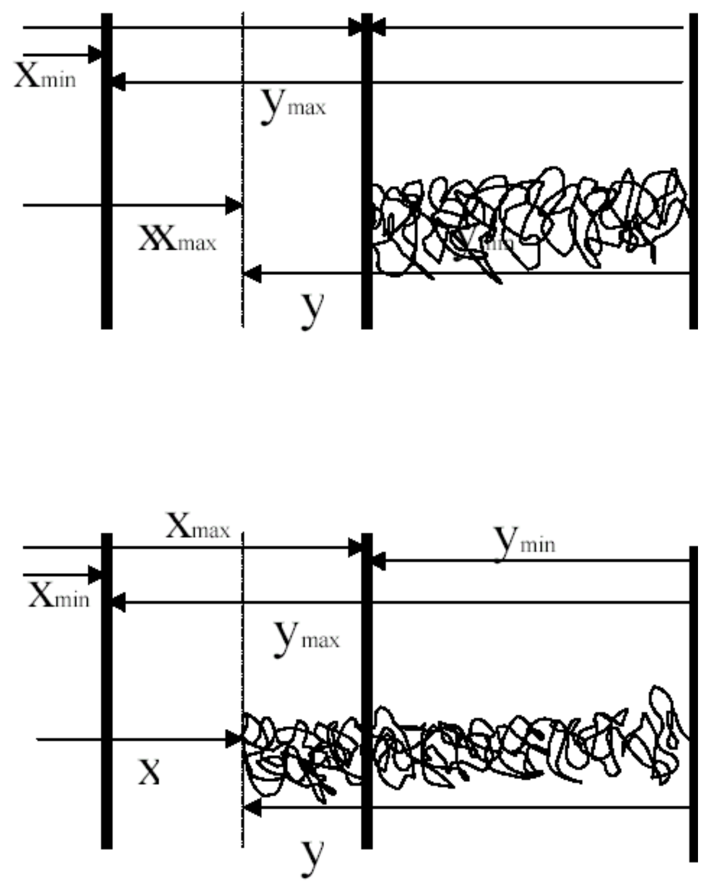


Figure 3

Thus, the corresponding differential equation for the x-region is:

$$\frac{dx}{dt} = k_1 x + k_2 x^2 - k_3 \frac{x^2}{y}$$

Similar considerations can be drawn for the y-region. As a result, a pair of coupled non-linear ordinary differential equations describe the way the change in pore size with time:

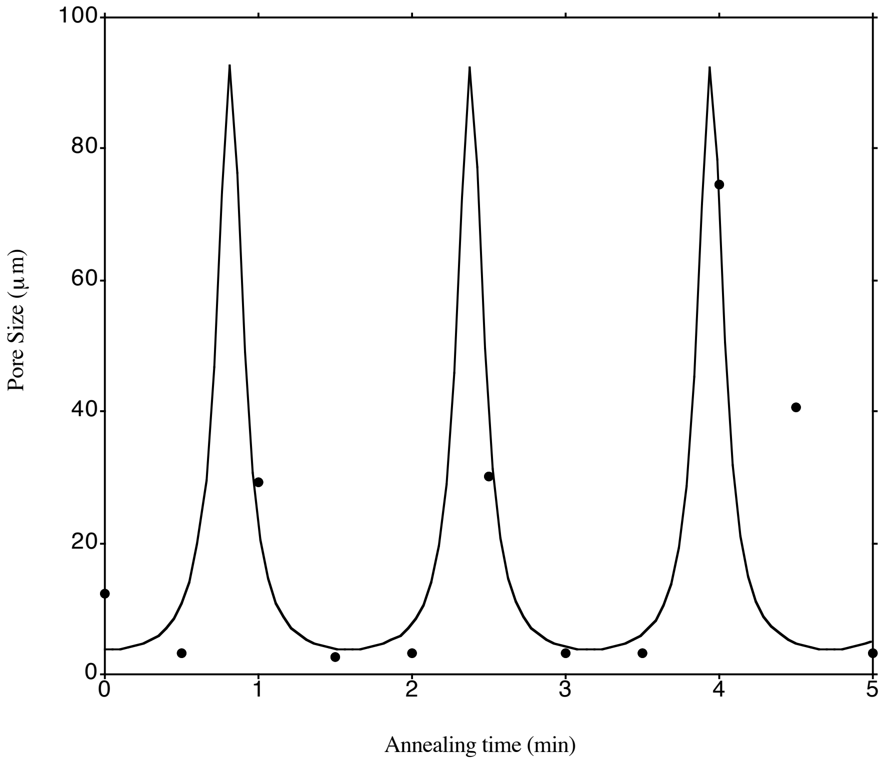
$$\frac{dx}{dt} = k_1 x + k_2 x^2 - k_3 \frac{x^2}{y} \qquad \frac{dy}{dt} = k_3 \frac{y^2}{x} - k_2 y^2 - k_1 y$$

The solutions to these equations are:

$$k_1 = \frac{\omega}{\delta}\left(1 - \frac{4}{3}\delta^2\right) \qquad k_2 = \frac{\omega}{\delta}(a+2)\delta^2 \qquad k_3 = \frac{\omega}{\delta}\left(1 + \frac{2}{3}\delta^2\right)$$

where □ is the phase difference. The relations between the ki’s and the parameters a, □, □ are given by:

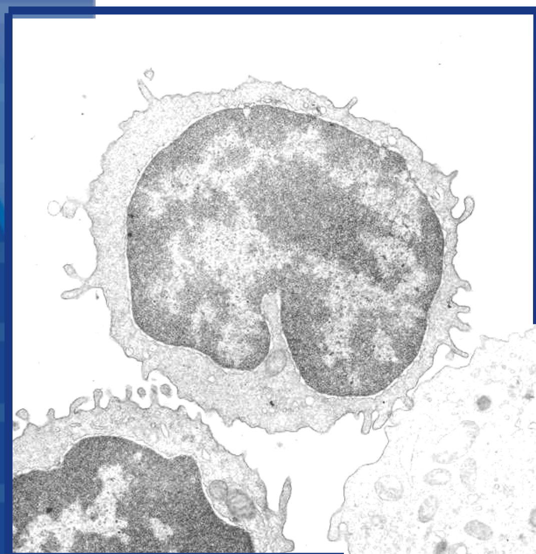
$$x(t) = \frac{x_o}{\left[1 + a\sin^2(\omega t)\right]} \qquad y(t) = \frac{y_o}{\left[1 + a\sin^2(\omega t + \delta)\right]}$$



100
80
60
40
20
0
0
1
2
3
4
5
Pore Size (μm)
Annealing time (min)

CONCLUSION:
A Modern Vision of Bioengineering

Biology



Chemistry

Physics

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