Big Impact of Small Science:
Nanotechnology and Bionanotechnology

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Learning in Retirement, 2018
Important Info

Course Information:
Wednesdays, April 18\textsuperscript{th} – May 23\textsuperscript{rd}
10:30 a.m. – 12:30 p.m. (15 minute break included)
Location: Room 124, Leeds House Building

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In today’s lecture, we will cover:

Overview of the lecture series

What is nanotechnology?

Where can I find nanotechnology?
Overview of Lecture Series

• Week 1: What is nanotechnology?
• Week 2: Nanoparticles
• Week 3: Nanotubes
• Week 4: Nanofilms
• Week 5: Bionanotechnology
• Week 6: Is nanotechnology safe?

Course materials will be available by email
Discussion and questions are encouraged!
Week 1: What is nanotechnology?

• Goals for this section:
  • Overview of history of nanotechnology
  • Examples of modern nanotechnology
  • “Top-Down” / “Bottom-Up”
  • Dimensionality and Association of Nanomaterials
What is nanotechnology?

- Nano = $10^{-9}$
- Nanometer is one billionth of a meter

- Nanoscience and nanotechnology are the study and manipulation of structures, devices, and phenomena on the length scale of less than 100 nanometers.
What is nanotechnology?

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- Nanoscience and nanotechnology are the study and manipulation of structures, devices, and phenomena on the length scale of less than 100 nanometers.
Our experience with the elements is mostly on the bulk scale

Meet the elements!!
But small is...different!

- Colours of noble metal nanoparticle solutions vs. the bulk metal
But small is...different!

- Fluorescence from different sized “quantum dots”
History of Nanotechnology?

Metallic nanoparticles in Stained Glass

http://www.nano.gov/timeline

Carbon nanotubes in a Damascus Sabre
So nanotechnology is not new -- our ability to understand it is

- How can we “see” at the nanoscale?
Special microscopes are required for nanotechnology

- Scanning or Transmission Electron Microscopes (SEM or TEM)
Transmission electron microscope

The transmitted beam is then detected. A scanning of the surface allows to visualize here again the magnified image of the sample.
Special microscopes are required for nanotechnology

- Atomic Force Microscopes (AFM)
Atomic Force Microscopy
Why are nanomaterials special?

• Greater surface area

• Quantum effects
These special properties lead to different behavior for nanomaterials.
What has driven nanotech?

http://philippe.ameline.free.fr/wordpress/?paged=7
What has driven nanotech?

If transistors were people

2,300
Average music hall capacity

134,000
Large stadium capacity

32 Million
Population of Tokyo

1.3 Billion
Population of China

1970
Intel 4004

1980
Intel 286

1990
Pentium III

2000
Core i7 Extreme Edition

Now imagine that those 1.3 billion people could fit onstage in the original music hall. That’s the scale of Moore’s Law.
Where can I find nanotechnology?

Where can I find nanotechnology?

Where can I find nanotechnology?

• Already found in many consumer products:
  • http://www.nanotechproject.org/cpi/
  • http://www.nanoandme.org/nano-products/
Some examples of nano-products

Miller Beer Bottles:
Clay nanoparticles in plastic beer bottles keep oxygen out and hold carbon dioxide in, preserving the beer.

Photo: sun dazed / Katy Warner / flickr

http://discovermagazine.com/galleries/zen-photo/n/nanotech-products
Some examples of nano-products

N-Force body armour:
Organic thin film on fibres strengthens the armor

Photo: First Choice Armor

http://discovermagazine.com/galleries/zen-photo/n/nanotech-products
Some examples of nano-products

Pregnancy Tests: Gold nanoparticles give the pink colour to positive pregnancy tests

Photo: Aaron Rowe

http://discovermagazine.com/galleries/zen-photo/n/nanotech-products
Some examples of nano-products

Eagle One Car Polish:
Nanoparticles of Palm Tree Wax give a clear coating that can fill tiny flaws and adhere strongly to paint.

Photo: Aaron Row

http://discovermagazine.com/galleries/zen-photo/n/nanotech-products
Some examples of nano-products

Quantum Dot TVs
New TVs are using quantum dots for sharper colors

Nano for medical applications

https://www.youtube.com/watch?v=6yDBApgrRSg
Potential Exposure Pathways

• We’ll look at the safety of nanomaterials in our last lecture

Basic concepts of nanotechnology

• “Top down” vs. “Bottom up”

• Dimensionality
  • Nanofilms
  • Nanotubes
  • Nanoparticles

• Association
  • Independent
  • Surface
  • Bulk
Top Down vs. Bottom Up

Top Down (solid state physics)
- The use of microfabrication (nanofabrication) techniques that reduce bulk material into smaller components to form nanoscale features or objects
- E.g. milling, lithography

Bottom Up (Chemistry)
- Synthesis of nanoscale structures and devices by chemically building up from the molecular level
- Self-assembly
Top Down vs. Bottom Up

Top Down (solid state physics)  Bottom Up (Chemistry)
Dimensionality of Nanomaterials

1°: *thin films* – the film can be considered beyond the nanometre scale in two dimensions (x,y), and nanoscale in the third (z).

2°: *rods, wires, and tubes* – these structures can be considered beyond the nanometre scale in one dimension (x), and nanoscale in the third (y,z).

3°: *particles* – all three dimensions are on the nanoscale (x,y,z).
Nanoscale Films and Coatings

- Hafnium oxide (HfO$_2$) thin film grown by atomic layer deposition (ALD).

Nanorods, Wires, and Tubes

- These are single-walled carbon nanotubes: graphene sheets (single atom layer thick sheet of carbon) rolled up onto itself.
- Depending on how you roll the tube, you can have different properties (conductor, semi-conductor or insulator).
Nanorods, Wires, and Tubes
Nanoparticles: Many Shapes and Properties

a) Nanorods

b) Nanoshells

c) Nanocages

d) Gold nano-particles of differing geometry

HfO₂ nanoparticle, shown in high-resolution TEM
Association of Nanomaterials

1: independent – the material is not physically attached to any substrate or moiety.

2: surface – the material is attached to the surface of a substrate. It might be "tethered" or more solidly associated.

3: bulk – the material is inside of a substrate or second material
Associations of 1°: Sheets and Films

1: *nanosheets* – it is typical to form these as a nanolaminate, or on a surface, and to then exfoliate the surface to free the nanosheet.

2: *thin films* – typically deposited, either by physical methods or chemical methods. Some examples have already been industrialized.

3: *nanolaminates* – again, these are typically deposited. Many examples of alternating or stacked sheets are known.
Associations of 2°: Rods, Wires, and Tubes

1: nanotubes – these are often grown using a quantum dot as a catalyst site. They may be very ordered or in a jumble.

2: nanowires – again, these might be etched or deposited. Pre-formed nanowires can be difficult to arrange on a surface.

3: nanocomposite – the material is inside of a substrate with distinct boundaries. These are typically cast.
Associations of 3°: Particles

1: *free nanoparticles* – these are typically formed in the vapour or solution phase. Conditions are typically very dilute to prevent aggregation.

2: *surface bound* – these might be etched or deposited, and are typically well-adhered to a surface. QDs are often made in ordered arrays

3: *nanocomposite* – the material is inside of a substrate with distinct boundaries. Typically, these are cast.
Comparison of nanotech products