Clays: Colloidal Properties in Nanodomain

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Why clay?

- The ever-growing application of clays in nanotechnology rests on fundamental principles of colloid chemistry.
- They make soils as nature’s great electrostatic chemical reactor.
- The unit cell dimensions of clay minerals are in nanometer scale in all three axes ($x$, $y$, and $z$).
Differences with other colloidal material

- Anisotropic and often irregular particle shape
- Broad particle size distribution
- Different types of charges within the unit cells
- Heterogeneity of layer charges
- Pronounced CEC
- Disarticulation and flexibility of layers
- Different modes of aggregation
advantages of clays

- their ordered arrangements,
- their large adsorption capacity,
- their shielding against sunlight (ultraviolet radiation),
- their ability to concentrate organic chemicals, and
- their ability to serve as polymerization templates.
Industrial uses of clay

- Petroleum refinery
- Cement
- Soaps, detergents, shampoos, lipsticks
- Pesticide carrier
- Ceramics, pottery and sculpture
- Fertilizer conditioner
- Environmental clean up operations
- Pharmaceuticals and catalyst
Nanomaterials

- either newly-created through nanotechnology, or that exist in nature

Example:
- clays, zeolites, imogolite, Fe & Mn oxides

Potential:
- to manipulate structures or other particles at the nanoscale and to control and catalyze chemical reactions
nanomaterial

Applications:
- provide transparency, or increased strength with decreased weight
- Smart fabrics
- Controlled Environment Agriculture
### Some successful ventures of nanotechnology involving clay

<table>
<thead>
<tr>
<th>Product</th>
<th>Application</th>
<th>Institution*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanocides</td>
<td>pesticides encapsulated in nanoparticles for controlled release</td>
<td>BASF</td>
</tr>
<tr>
<td></td>
<td>nanoemulsions for greater efficiency</td>
<td>Syngenta</td>
</tr>
<tr>
<td>Bucky ball fertilizer</td>
<td>ammonia from buckyballs</td>
<td>Kyoto Univ, Japan</td>
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<tr>
<td>Nanoparticles</td>
<td>Adhesion-specific nanoparticles for removal of <em>Campylobacter jejuni</em> from poultry</td>
<td>Clemson Univ.</td>
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<tr>
<td>Food packaging</td>
<td>airtight plastic packaging with silicate nanoparticles</td>
<td>Bayer</td>
</tr>
<tr>
<td>Use of agricultural waste</td>
<td>nanofibres from cotton waste for improved strength of clothing</td>
<td>Cornell univ</td>
</tr>
<tr>
<td>Nanosensors</td>
<td>contamination of packaged food</td>
<td>Nestle, Kraft</td>
</tr>
<tr>
<td></td>
<td>pathogen detection</td>
<td>Cornell Univ</td>
</tr>
<tr>
<td>Precision agriculture</td>
<td>nanosensors linked to GPS for real-time monitoring of soil conditions and crop growth</td>
<td>USDA</td>
</tr>
<tr>
<td>Live stock and fisheries</td>
<td>nano-veterinary medicine (nanoparticles, buckyballs, dendrimers, nanocapsules for drug delivery, nanovaccines; smart herds, cleaning fish ponds (Nanocheck); feed (iron nanoparticles)</td>
<td>Cornell Univ, Nanovic, Australia</td>
</tr>
</tbody>
</table>
Possible innovations

- nano-enhanced products (e.g. nanofertilizers and nanopesticides)
- nano-based smart delivery system (use of halloysite)
- Nanoporous materials (e.g. hydrogels and zeolites)
- nanoporous membranes
- Nanosorbents
- Nanocrystals of magnetite (< 12 nm)
- Nanosensors
- nanoscale precision farming
Soil mineral structures
d = r (cation) + r (anion)
Si-tetrahedron and Al-octahedron structure
Si tetrahedra and Al octahedra in clay minerals

The Mystery of Clays - Eytons' Earth
Structure of kaolinite (China clay)
Structure of Montmorillonite: 

\[
\text{MONTMORILLONITE} \quad (\text{Al}_{3.2}\text{Mg}_{0.8})(\text{Si}_{8}\text{O}_{20}(\text{OH})_4 \times 0.8
\]

\[
\text{Na}^+ / \text{Ca}^{++}
\]

**Tetrahedral**

\[
\begin{array}{c}
\text{Si} \\
\text{O}
\end{array}
\]

6 O
4 Si

**Octahedral**

\[
\begin{array}{c}
\text{Al}^{+++} \\
\text{OH}
\end{array}
\]

3.2 \text{Al}^{+++} + 0.8 \text{Mg}^+
4 O + 2 OH

**Tetrahedral**

\[
\begin{array}{c}
\text{Si} \\
\text{O}
\end{array}
\]

4 Si
6 O
Tectosilicates: Zeolite
TEM of a zeolite
Birth of semiconductivity
Promises of nanotechnology

- greatest technological breakthrough in history, doing for our control of matter what computers did for our control of information.

- Though limits to growth will remain, we will be able to harvest solar power a trillion times greater than all the power now put to human use.
Defining nanotechnology

- is a new interdisciplinary venture-field that converge science, engineering, and agriculture and food systems into one –
  Dr. APJ Abdul-Kalam

- understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible (EPA, 2007).
What will nano materials do to the environment?

- Our expanding ability to synthesize nanoparticles for use in electronics, biomedical, ceramics, pharmaceutical, cosmetic, energy, environmental, catalytic, material etc. has alarmed concern for these particles role in various areas.

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount of Engineered material used</th>
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<tbody>
<tr>
<td>2004</td>
<td>2000 tons</td>
</tr>
<tr>
<td>2011-2020</td>
<td>58000 tons (expected)</td>
</tr>
</tbody>
</table>

Zeophonics

- System founded on the concept of interconnected nature of all life-forms and life-support-forms
- Relies on recycling and operation of system-components
- The system provides a framework where impetus and response are almost equal.
This is the only means of survival in the extraterrestrial planets, space stations, and in the Antarctica
Nanotechnology in agriculture is like a game of Quiddich that Harry Potter and other pupils played in the School of Magic. No matter what’s the score, if the seeker catches snitch, his team wins.
Thank you!