An Introduction to Catalysis and Surface Science

Science dialogue with the students of Tsuru high school in Yamanashi prefecture.

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Graduate School of Science
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Tokyo 113-0033, Japan

12 June 2007

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- Nanotechnologies

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- Homogeneous or heterogeneous catalysis
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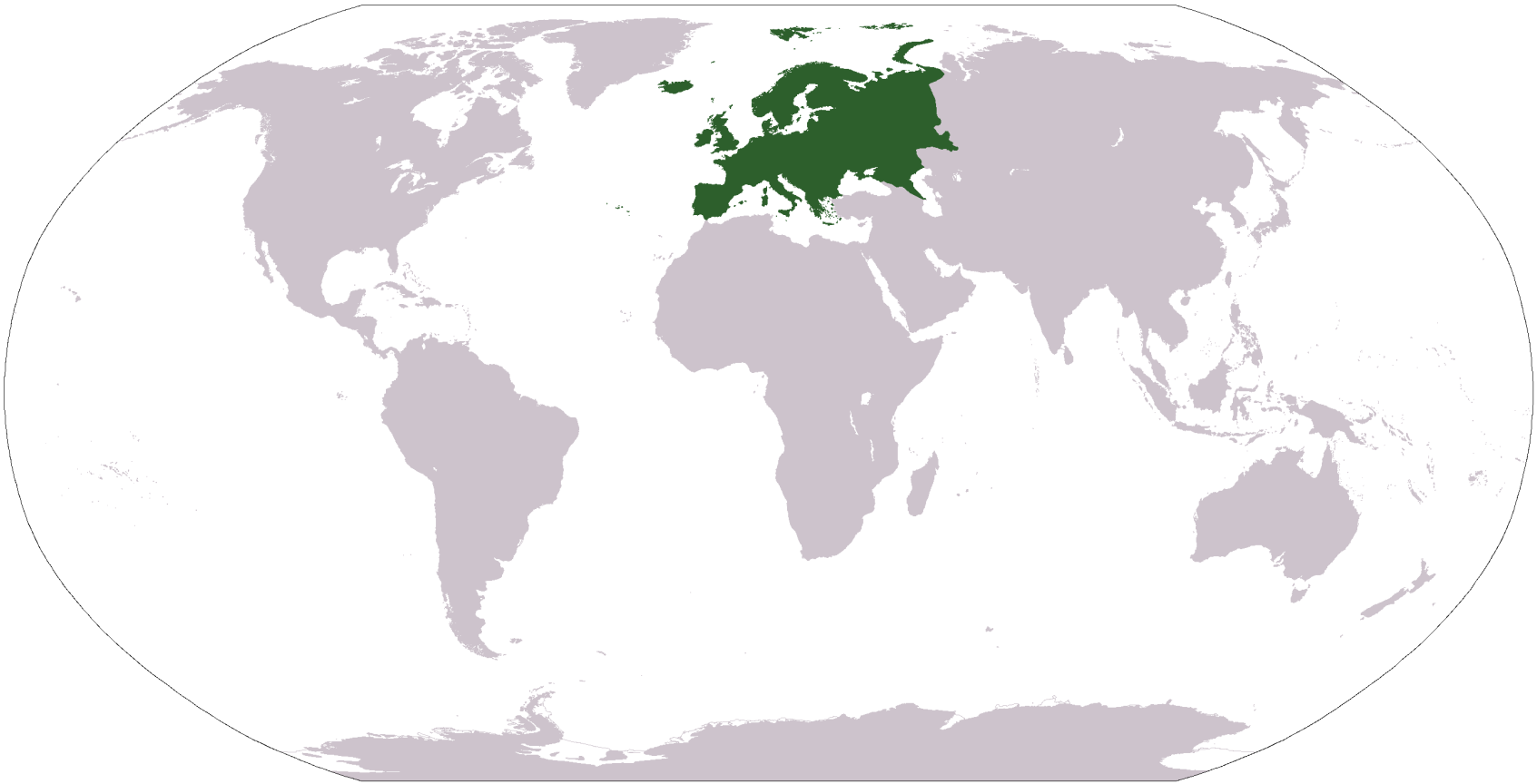
Intelligent materials
- Windows
- Nanotechnologies

Location of Europe



Satellite view of Europe

Dijon, where I was born...

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. . . and where I studied

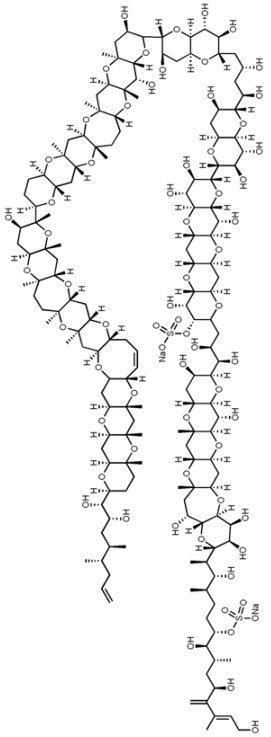
Université de Bourgogne

DEUG Biologie organic chemistry

Licence de Chimie inorganic chemistry

Maîtrise Matériau materials science

DEA Chimie-physique materials science and physical chemistry



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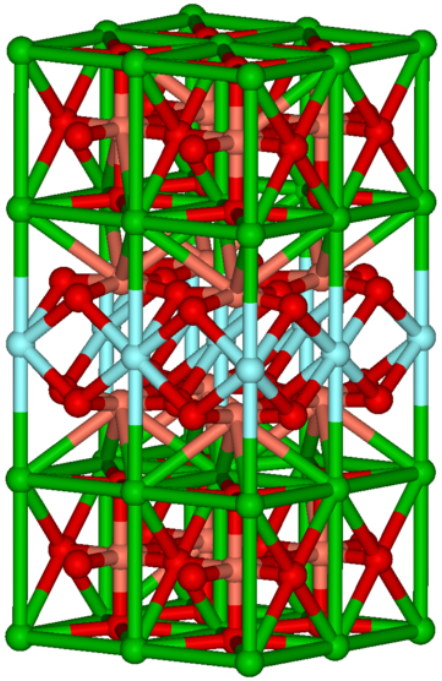

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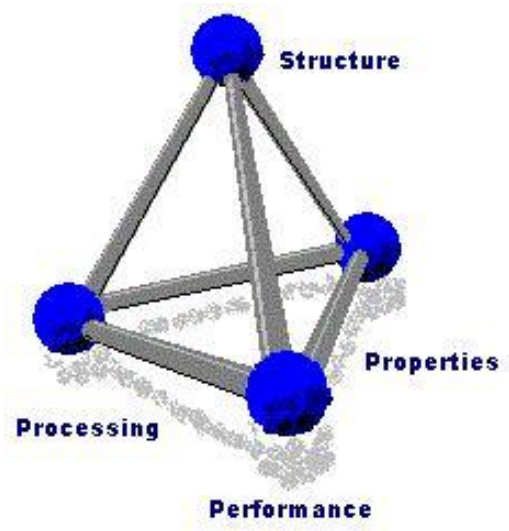

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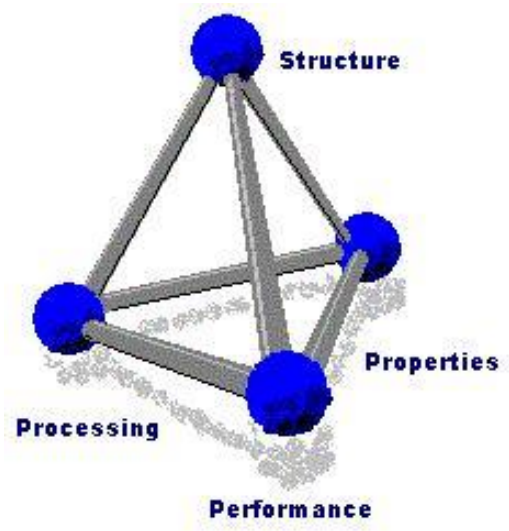
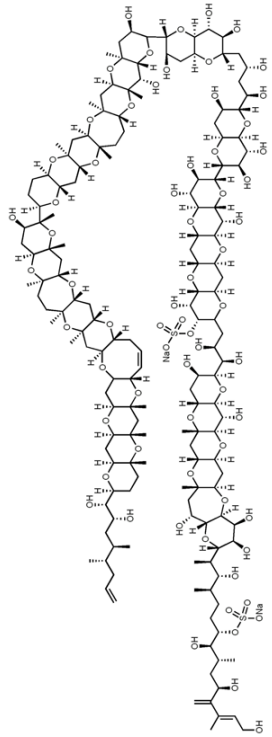


From chemistry to materials science



Pharmacy, food, petrochemicals. . .

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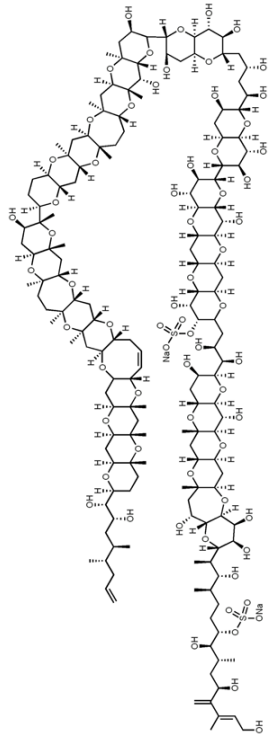

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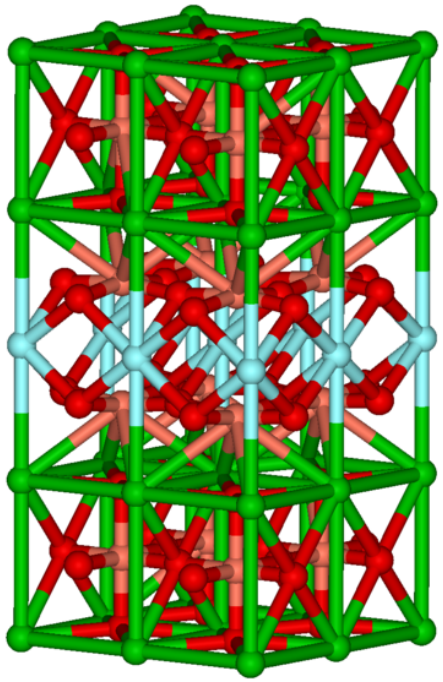

Environment, minerals, solid state...

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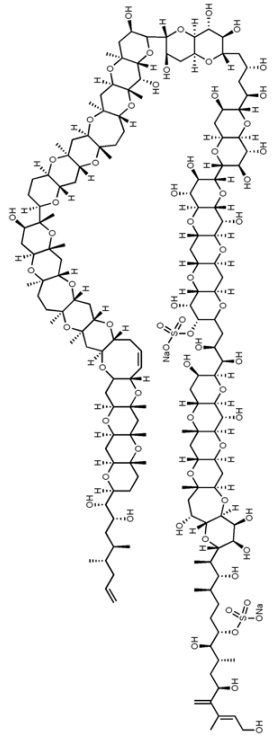

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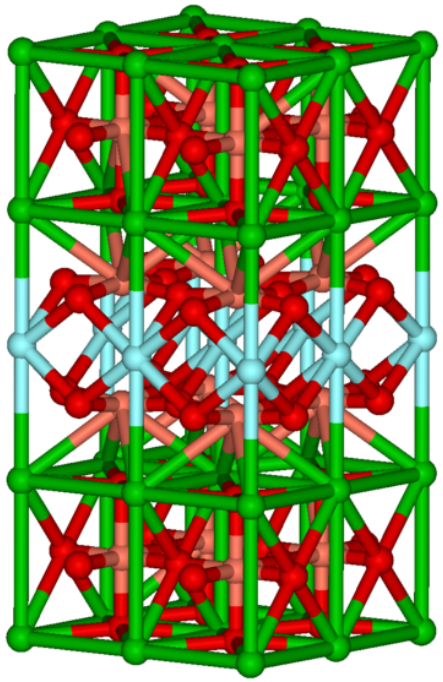

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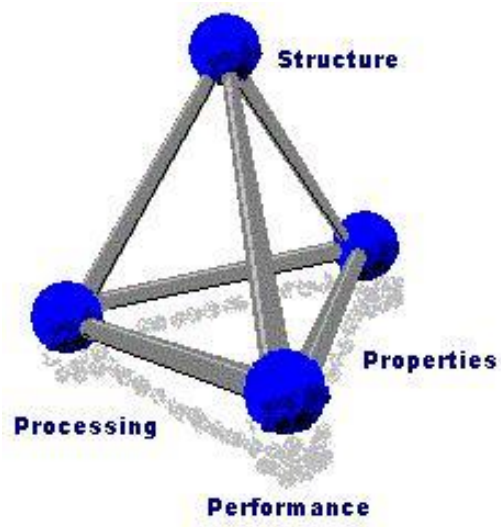
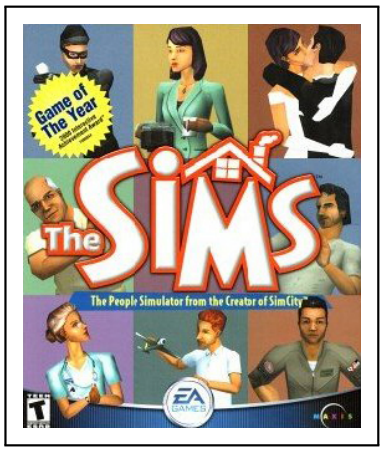


Plastics, metallurgy, ceramics, polymers...

Chemometrics at the Katholieke Universiteit Nijmegen

Applying artificial intelligence. . .



The Sim's

Kasparov vs. Deep Blue

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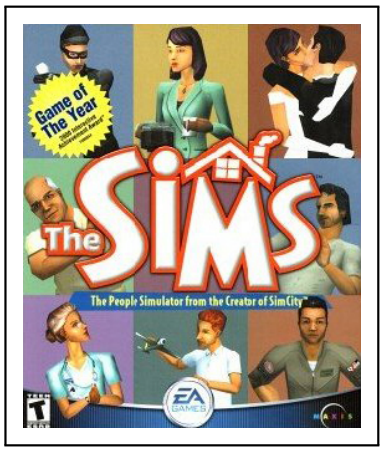

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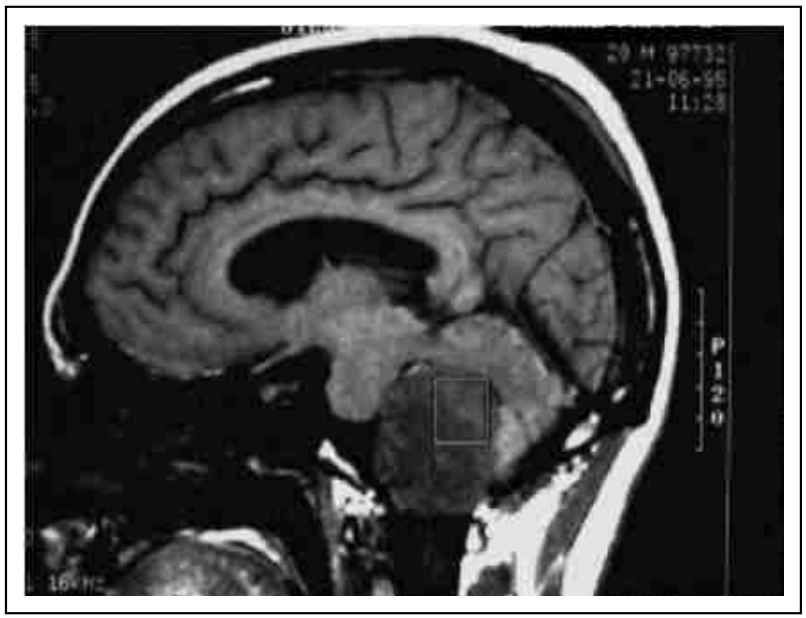
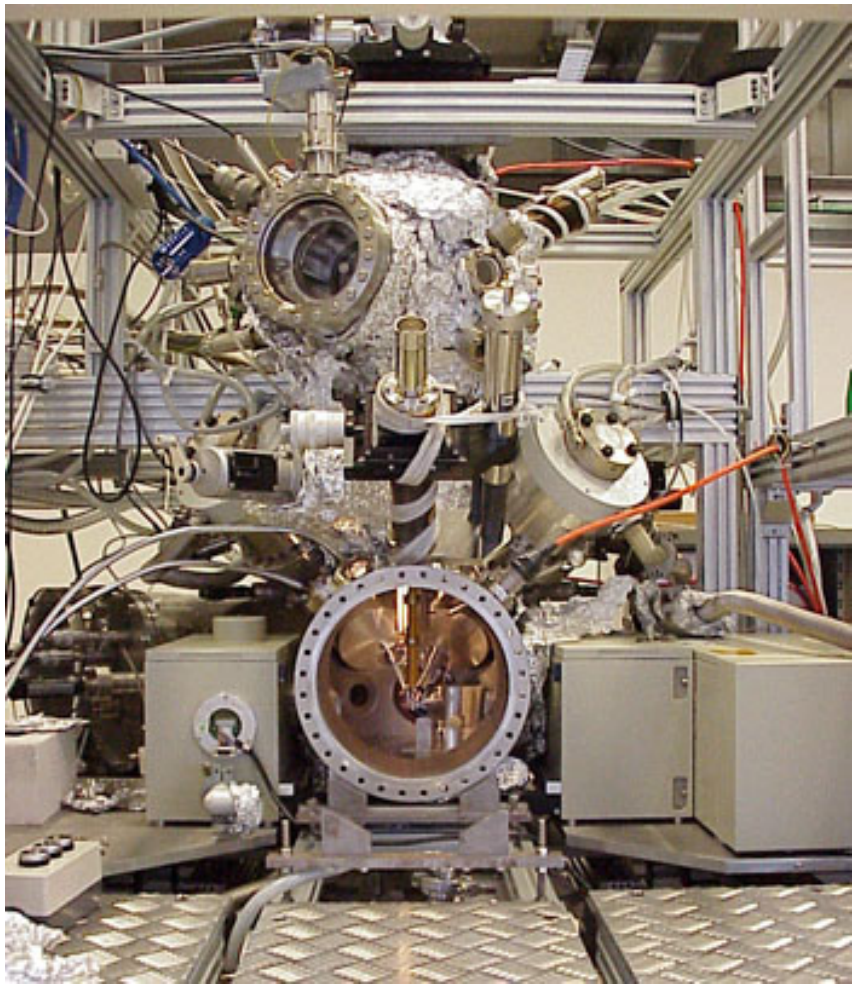

MRI Brain tumor

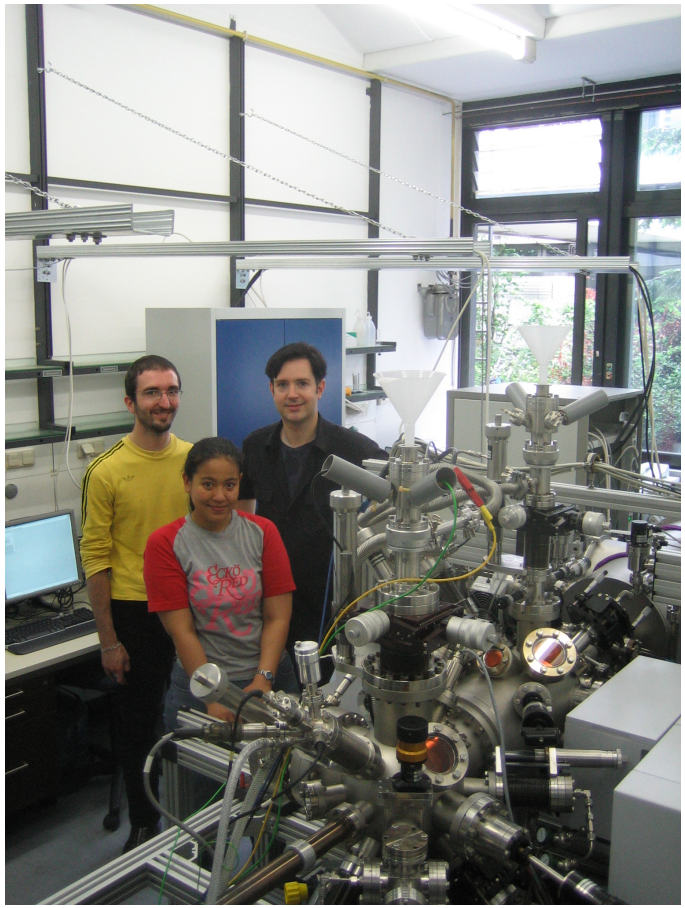
. . . to biology and chemistry.

Berlin

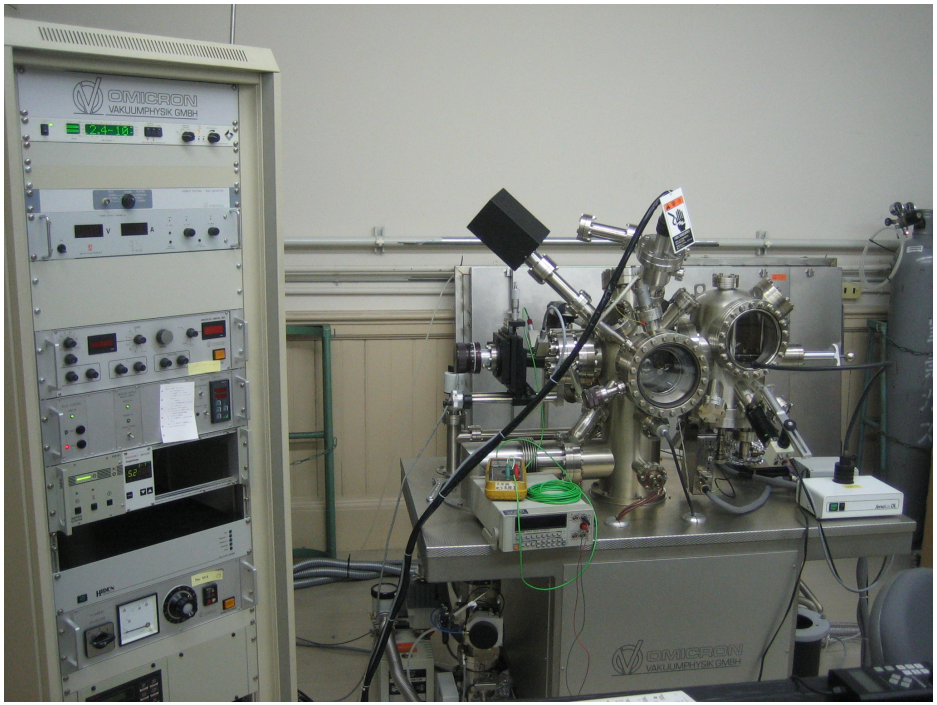
Fritz-Haber-Institut der Max-Plank-Gesellschaft

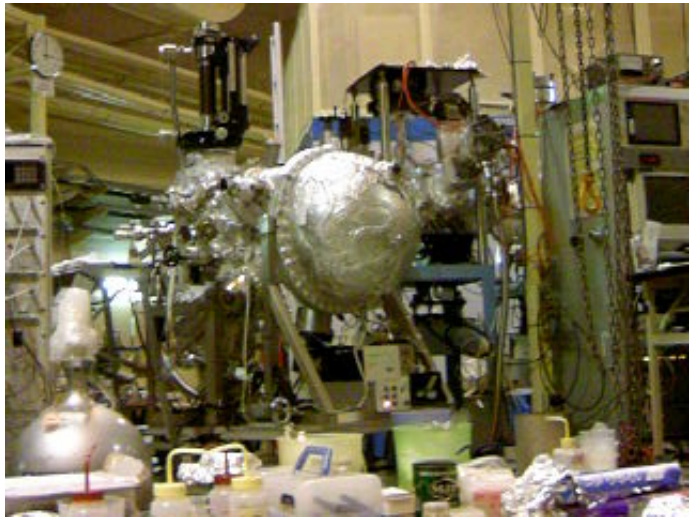


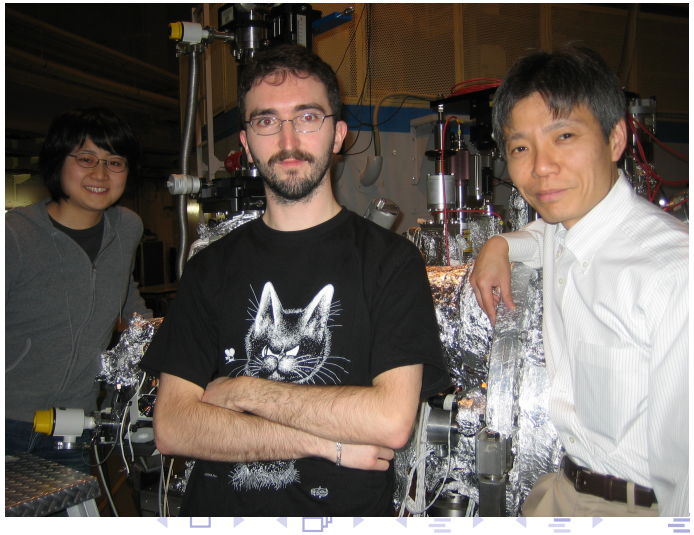
Erlangen: Building a UHV apparatus



The University of Tokyo







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What is catalysis?

All chemical processes in biology and chemistry rely on catalysis.

In a (bio)chemical process, catalysis

- modifies the kinetics for the reaction;
- modifies the pathway of the reaction;
- tunes a reaction toward a specific product.

The catalyst will modify the way the reaction if performed but will be involved in neither reactants nor products.

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History (wikipedia)

The phrase catalysis was coined by Jöns Jakob Berzelius who in 1835 was the first to note that certain chemicals speed up a reaction. Other early chemists involved in catalysis were Alexander Mitscherlich who in 1831 referred to contact processes and Johann Wolfgang Döbereiner who spoke of contact action and whose lighter based on hydrogen and a platinum sponge became a huge commercial success in the 1820s. In the 1880s, Wilhelm Ostwald at Leipzig University started a series of systematic investigations into reactions that were catylized by the presence of acids and bases, and found both that chemical reactions occur at finite rates, and that these rates can be used to determine the strengths of acids and bases. For this work, Ostwald was awarded the 1909 Nobel Prize in Chemistry.

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Homogeneous or heterogeneous catalysis

Different types of catalysts:

Homogeneous catalysts catalyst, reactants and products in the same phase (e.g. all liquids).

Heterogeneous catalysts catalyst in a separate phase (e.g. solid catalyst of a gaseous reaction.

Obvious advantage of heterogeneous catalysts: the homogeneous catalysts needs to be removed after the reaction is performed!

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Real-world example

Two sunny days on Beijing

and Los Angeles

Car exhaust system...

Three main reactions are being catalysed at the same time

- $2CO_{(g)} + O_{2(g)} \rightarrow 2CO_{2(g)}$
- $2NO_{(g)} + 2CO_{(g)} \rightarrow N_{2(g)} + 2CO_{2(g)}$
- $C_6H_{6(g)} + 7\frac{1}{2}O_2 \rightarrow 6CO_{2(g)} + 3H_2O_{(l)}$

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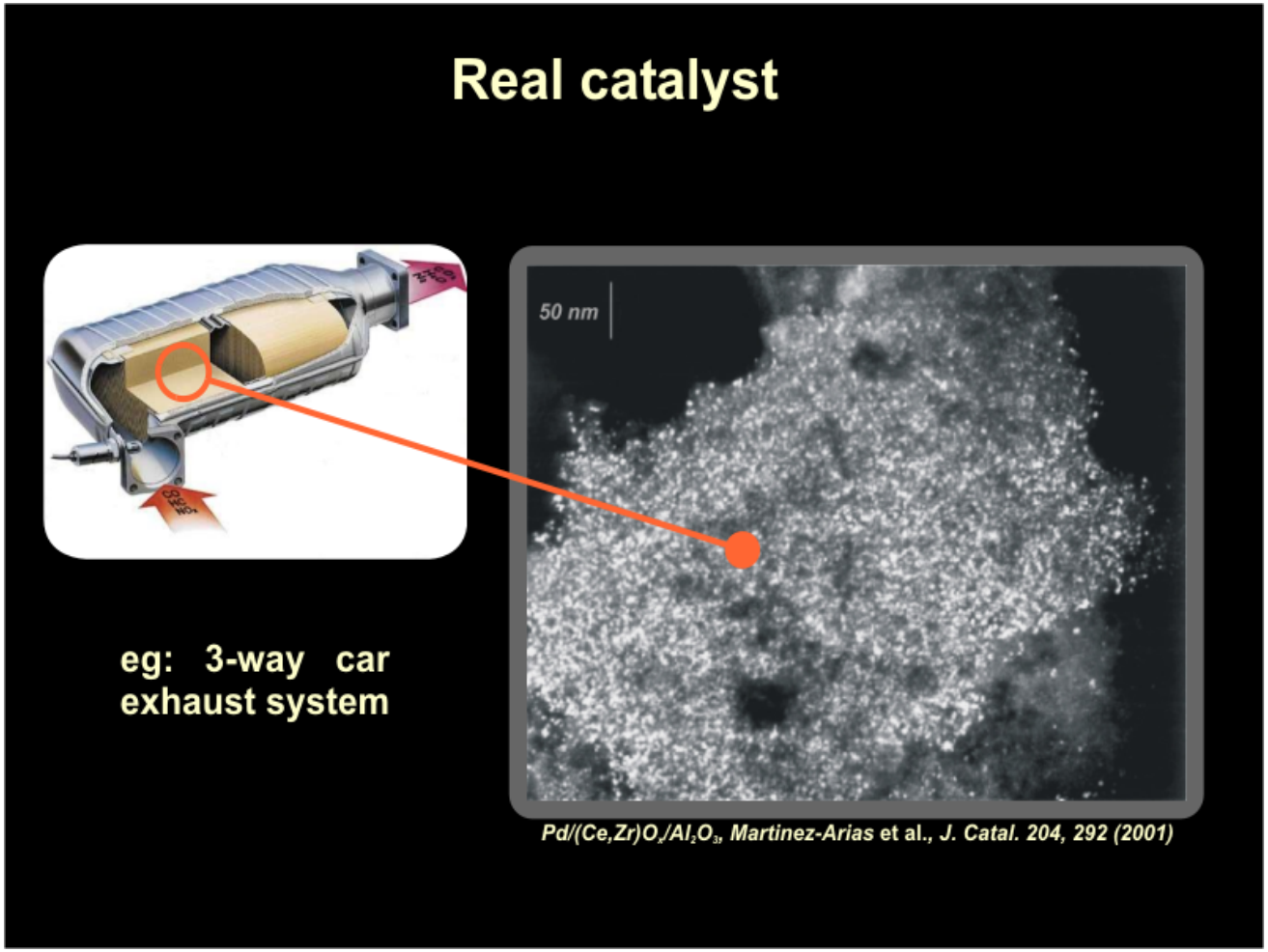
. . . and the catalyst itself



Ingeneering

Do you want to improve its performance?

Typically, heterogeneous catalysis is a complex process

1. take an old one
2. change a few of its properties
3. try the new catalyst
4. try 100+ new catalysts
5. sell the best one

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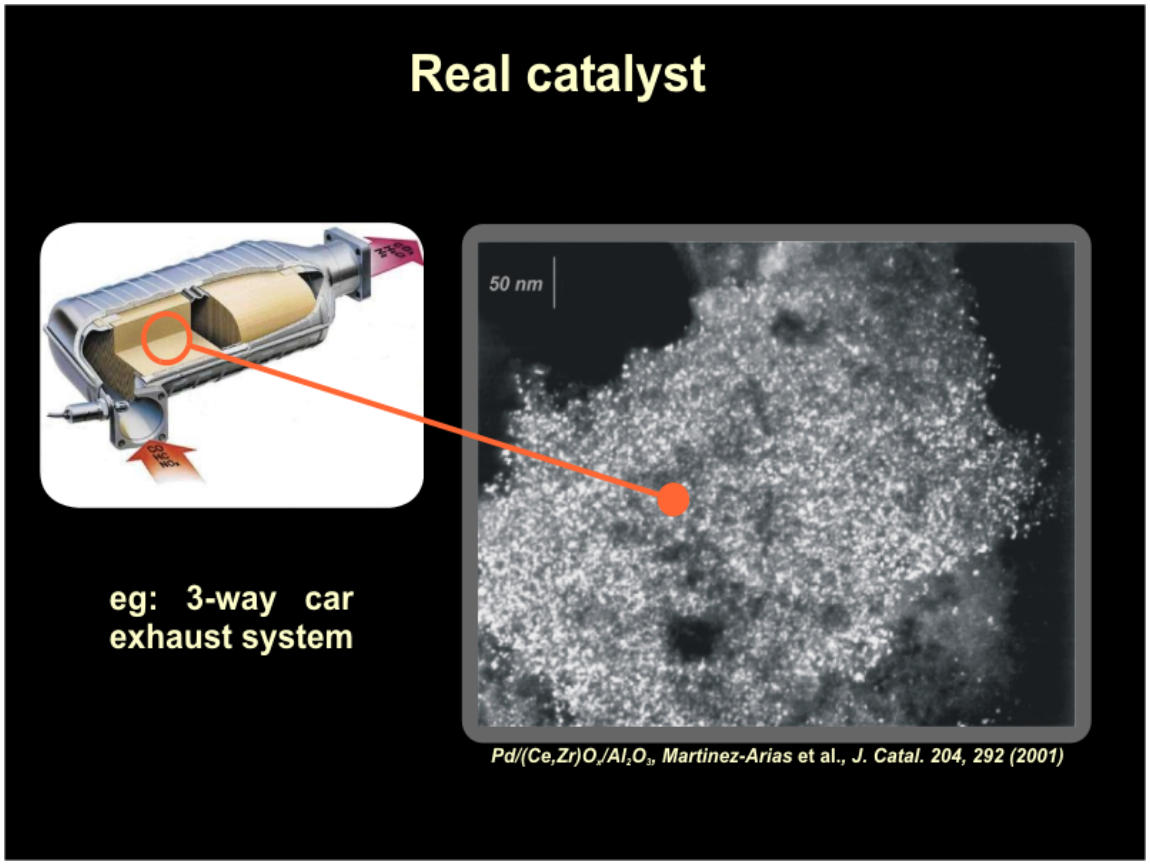
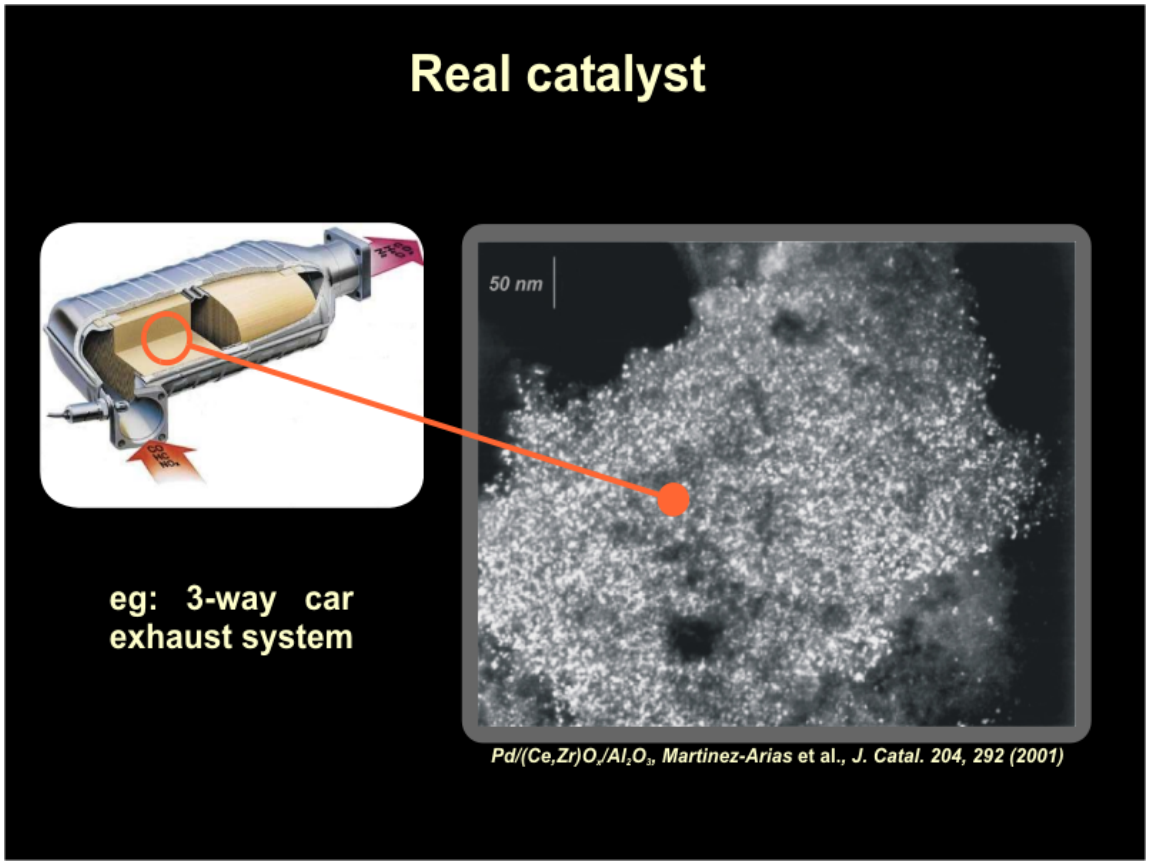
Conclusion



And what if. . .

. . . we could understand what happens at this surface?

Conclusion



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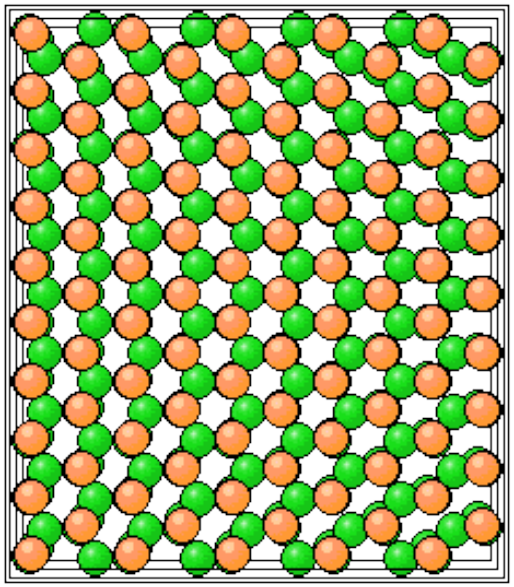
Studying surfaces

Because not only the chemical reactions are complex but the surface itself is!

(e.g. Si)



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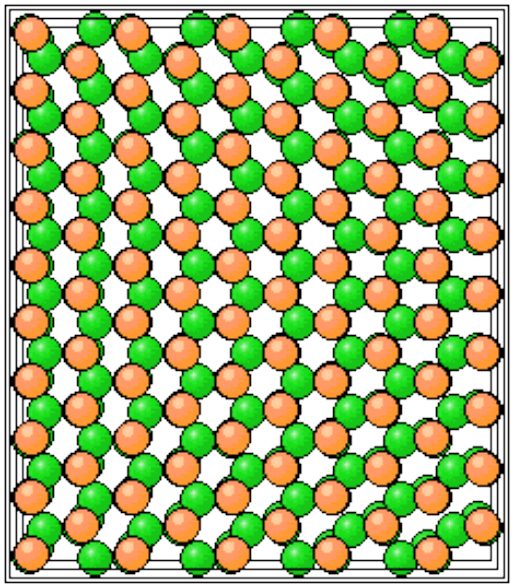
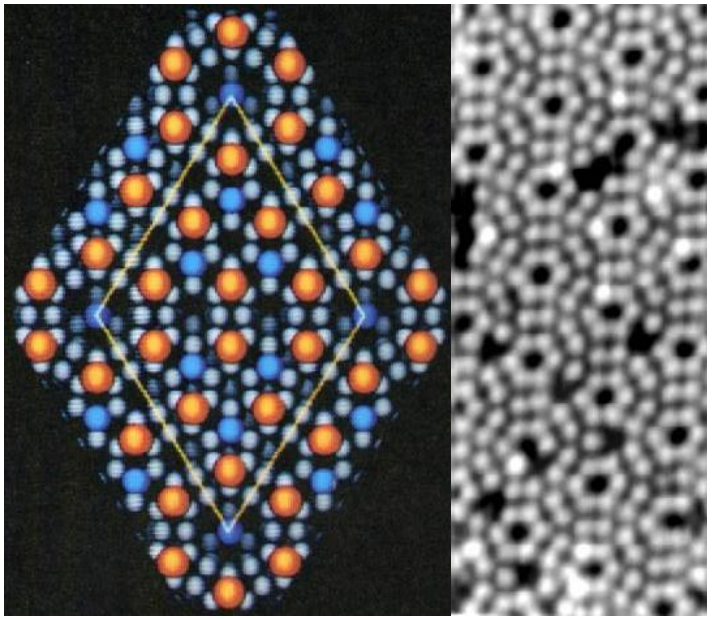
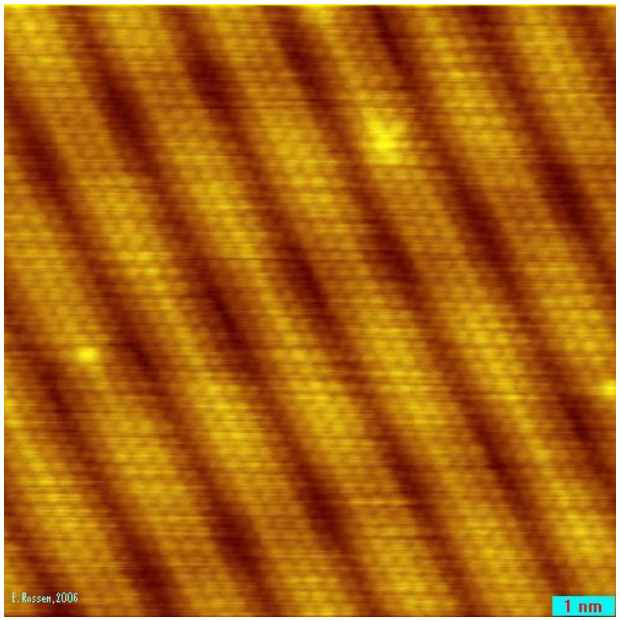




Complex surfaces

(e.g. Au)



Very simple surfaces and realistic surfaces!

Complex surfaces

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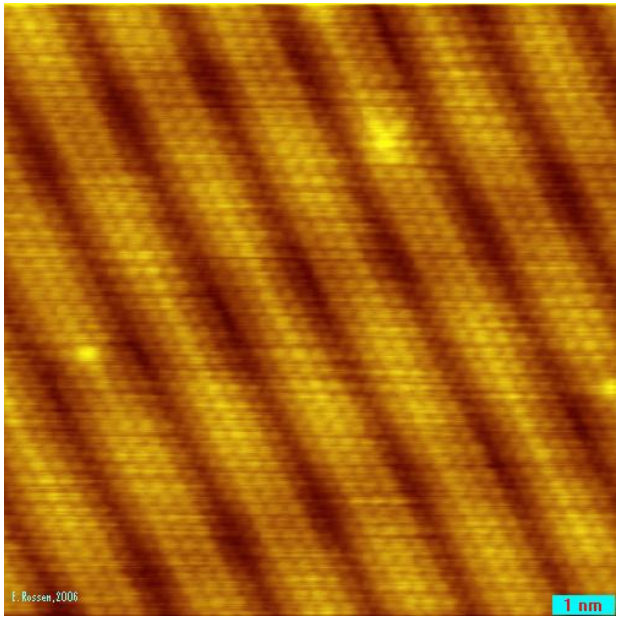

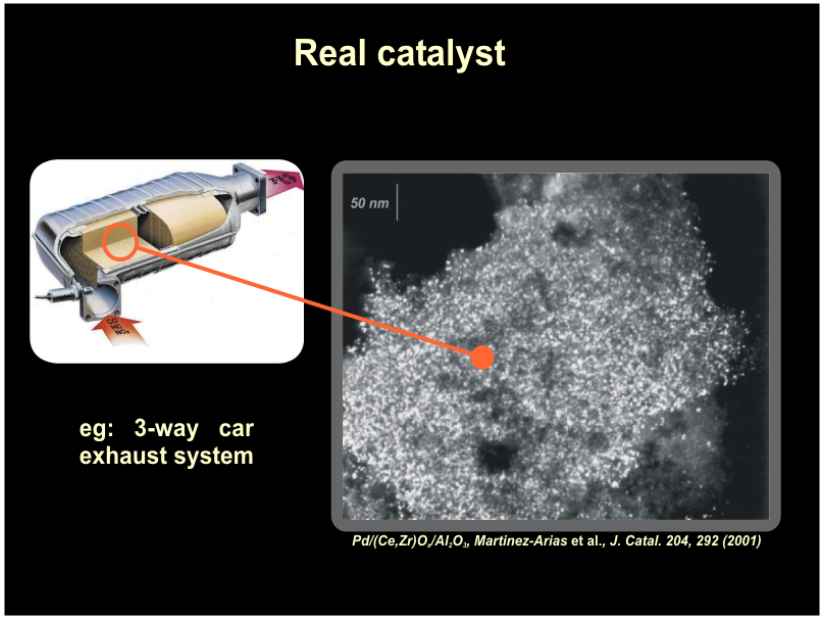

Very simple surfaces and realistic surfaces!

Studying complex reactions at complex surfaces?

. . . or breaking the problem into pieces

Work under vacuum, use simpler surfaces with known properties, and simple reaction. . .

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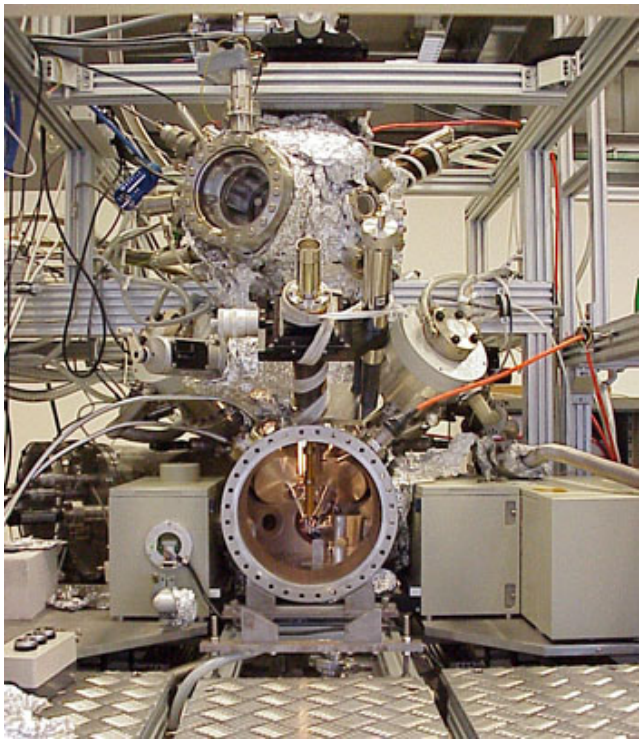

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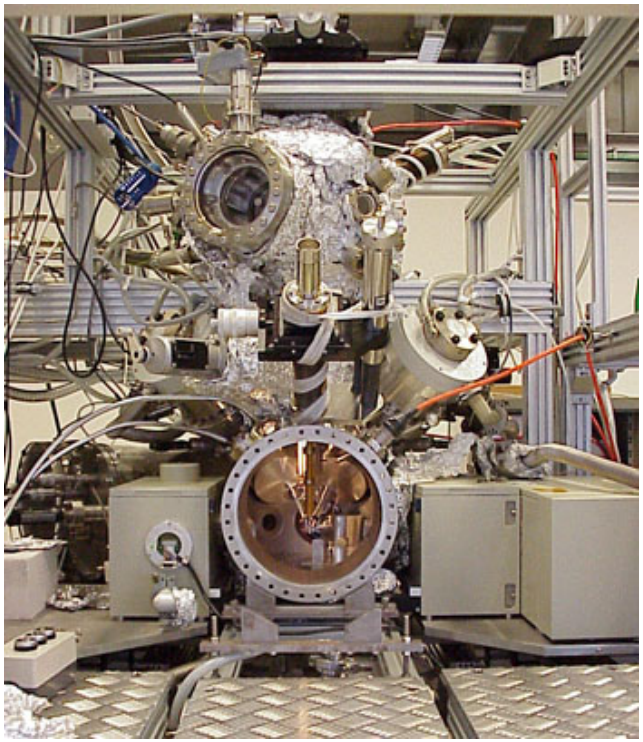

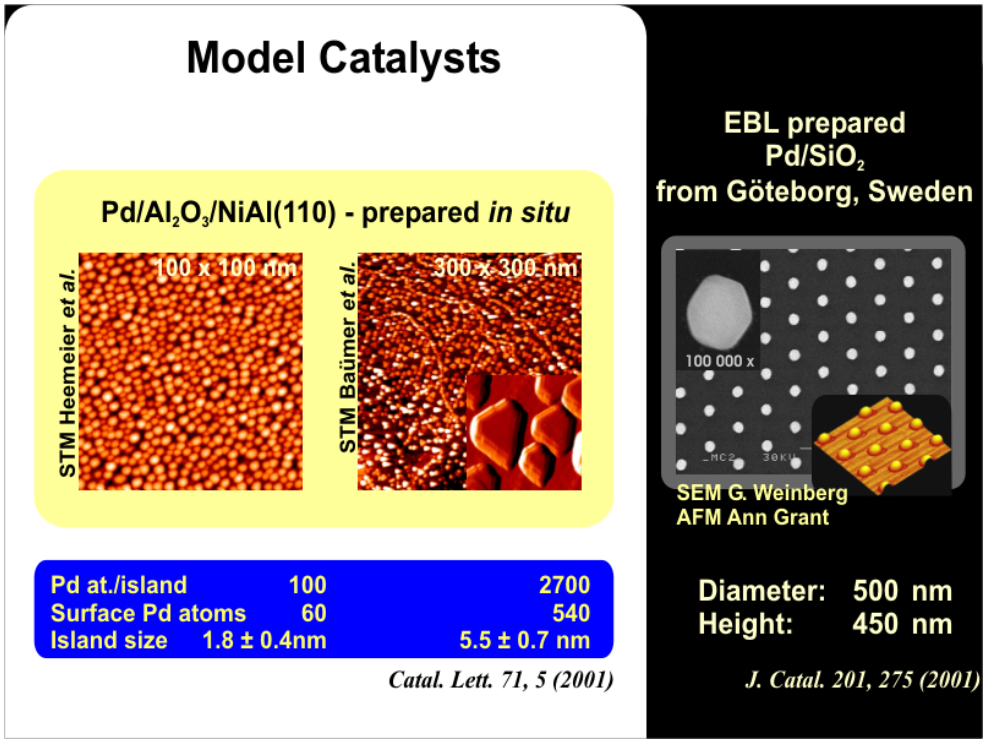

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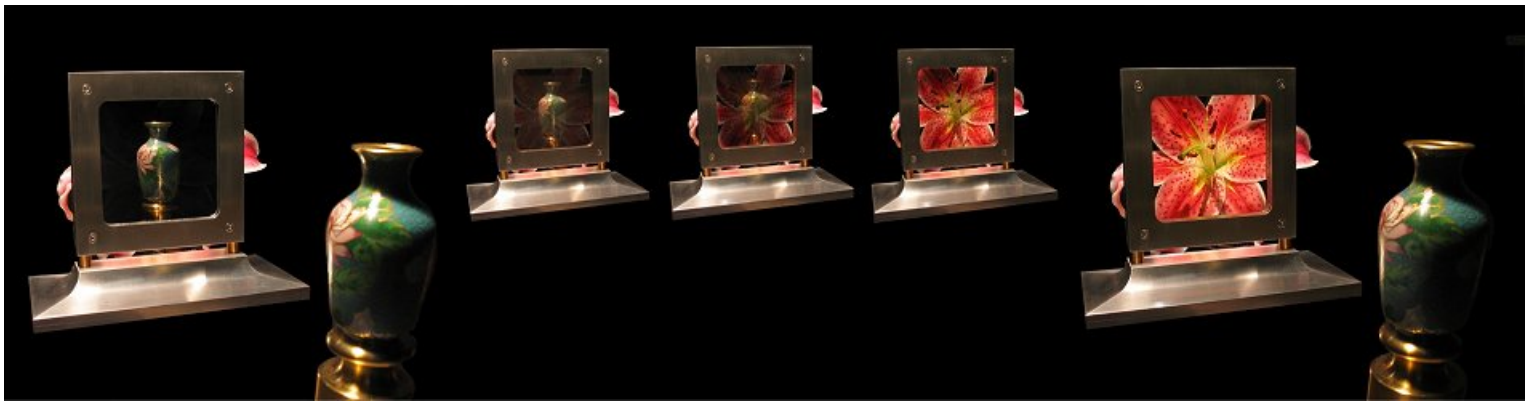
Self-cleaning materials

from St. Gobain

A window covered with an invisible coating of catalyzer which destroys the organic dirt as it is deposited.

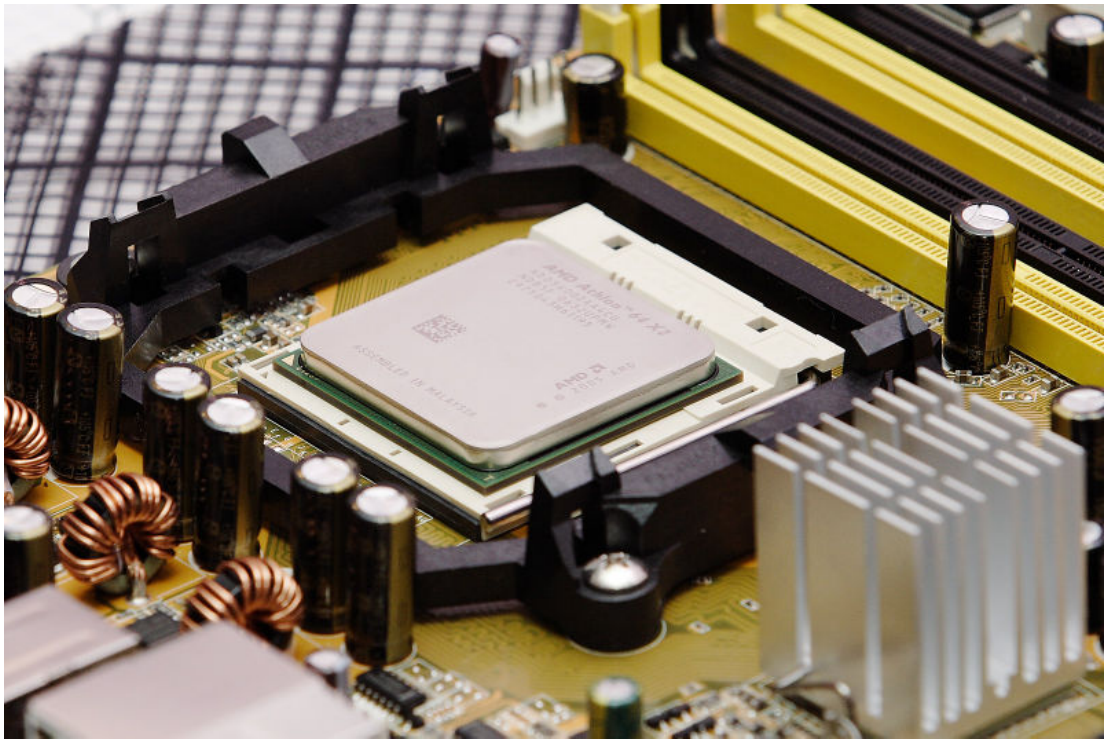
Energy savings



Mirror or window?

from the Windows and Daylighting Group at Lawrence Berkeley National Lab.

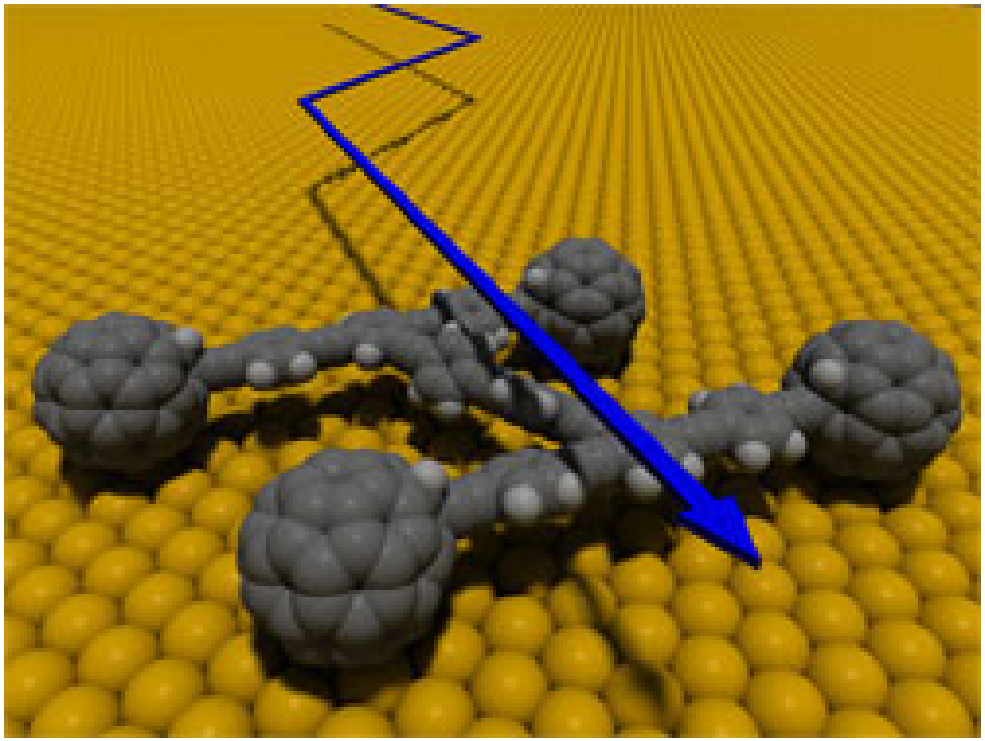
CPU chip



CPU chip layout based on surface science

AMD X2 3600

The nanocar



Prof. James Tour's nanocar, Rice University

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