An Introduction to Catalysis and Surface Science

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

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Table of Contents

Introduction

Catalysis
  What is catalysis?
  Homogeneous or heterogeneous catalysis
  Example of heterogeneous catalysis
  Ingeneering?

Surface Science
  Complex surfaces
  Complex reactions at complex surfaces

Intelligent materials
  Windows
  Nanotechnologies
Outline

Introduction

Catalysis
What is catalysis?
Homogeneous or heterogeneous catalysis
Example of heterogeneous catalysis
Ingeneering?

Surface Science
Complex surfaces
Complex reactions at complex surfaces

Intelligent materials
Windows
Nanotechnologies

Dr. Mathias Laurin
An Introduction to Catalysis and Surface Science
Location of Europe
Satellite view of Europe
Dijon, where I was born...
Dijon, where I was born...
... and where I studied

Université de Bourgogne
DEUG Biologie  organic chemistry
Licence de Chimie  inorganic chemistry
Maîtrise Matériaux  materials science
DEA Chimie-physique  materials science and physical chemistry
... and where I studied

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From chemistry to materials science

Pharmacy, food, petrochemicals...
From chemistry to materials science

Pharmacy, food, petrochemicals... Environment, minerals, solid state...
From chemistry to materials science

Pharmacy, food, petrochemicals...

Environment, minerals, solid state...

Plastics, metallurgy, ceramics, polymers...
Chemometrics at the Katholieke Universiteit Nijmegen

Applying artificial intelligence...

The Sim’s

Kasparov vs.
Deep Blue
Chemometrics at the Katholieke Universiteit Nijmegen

Applying artificial intelligence... 

The Sim’s

Kasparov vs. Deep Blue

MRI Brain tumor

... to biology and chemistry.
Berlin
Fritz-Haber-Institut der Max-Plank-Gesellschaft

An Introduction to Catalysis and Surface Science
Erlangen: Building a UHV apparatus
The University of Tokyo
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Surface Science
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Intelligent materials
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  Nanotechnologies
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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The catalyst will modify the way the reaction if performed but will be involved in neither reactants nor products.
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 catalyzed 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

- \(2 \text{CO}(g) + \text{O}_2(g) \rightarrow 2 \text{CO}_2(g)\)
- \(2 \text{NO}(g) + 2 \text{CO}(g) \rightarrow \text{N}_2(g) + 2 \text{CO}_2(g)\)
- \(\text{C}_6\text{H}_6(g) + 7\frac{1}{2} \text{O}_2 \rightarrow 6 \text{CO}_2(g) + 3 \text{H}_2\text{O}(l)\)
Car exhaust system...

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- \(2NO(g) + 2CO(g) \rightarrow N_2(g) + 2CO_2(g)\)
- \(C_6H_6(g) + 7\frac{1}{2}O_2 \rightarrow 6CO_2(g) + 3H_2O(l)\)
... and the catalyst itself

Real catalyst

eg: 3-way car exhaust system

Pd/(Ce,Zr)O/Al₂O₃, Martinez-Arias et al., J. Catal. 204, 292 (2001)
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
Do you want to improve its performance?

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And what if...

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

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… we could understand what happens at this surface?
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Studying surfaces

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

(e.g. Si)
Studying surfaces

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

(e.g. Si)
(e.g. Au)

Very simple surfaces and realistic surfaces!
Complex surfaces

(e.g. Au)

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...
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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Self-cleaning materials

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

from St. Gobain
Energy savings

Mirror or window?

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

An Introduction to Catalysis and Surface Science

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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- Wikipedia (most of the pictures in this presentation)