Heterogeneous Catalysis

Evan Chen, Renata Bence and Luis López Rojas

What is heterogeneous catalysis?

The phase of the catalysts differs from that of the reactants or products. The process occurs at the catalyst surface, involving cycles of molecular adsorption, reaction, and desorption.
The catalyst can be dispersed onto a high surface area material called a support (typically silica, alumina or carbons).

Did you know that... Heterogeneous catalysis is responsible of almost 90% of the total volume of chemical production each year, making it one of the most profitable industrial sectors worldwide.

Easy separation, high recyclability

Heterogeneous catalysts can be removed through simple separation techniques, such as filtration, and can be recovered for great reusability.

Temperature? Pressure? No problem

These catalysts exhibit high resiliency in elevated temperatures and pressures.

Just go with the flow

Usable with continuous flow chemistry, leading to highly efficient processes.

Difficult fabrication

Heterogeneous catalysts are more difficult to assemble. The structure is less well-defined and requires the uniform deposition of the active catalyst onto a suitable solid support.

Prone to poisoning

Deposition of inactive materials onto the catalyst surface reduces catalyst activity over time.

1800s — Early heterogeneous catalysts consisted of metal powders

1895 — Friedrich Wilhelm Ostwald introduces the concept of catalysis

1910 — Development of the Haber-Bosch process; the first industrial process using heterogeneous catalysis

1927 — The principles of Langmuir-Hinshelwood kinetics were published

1950-1970 — The catalytic process for "cracking" petroleum was developed by Eugene Houdry

Development of catalysts for petroleum processing, polymerization, and catalytic converters.

Catalyst design (choice of materials, composition, porosity, etc) emerges as a result of the understanding of mechanisms, exploration of new materials and advances in supports

1980s — The rise of computing enabled prediction of rate constants and catalyst properties using quantum mechanics

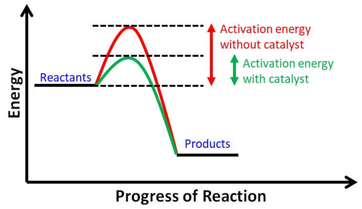
1990s — Molecular characterization of surfaces led to advances in modelling and understanding of catalyst leading to improved performance

2000s — **What's next?**

Ongoing research to optimize catalyst design and efficiency for a more sustainable future.

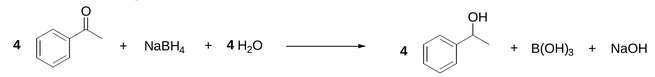
Catalysis is the 9th principle of green chemistry

"Catalytic reagents (as selective as possible) are superior to stoichiometric reagents".



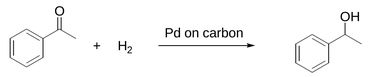
Accelerates chemical reactions, allowing them to occur at lower temperatures and pressures.

Without catalyst



81% atom economy

With catalyst



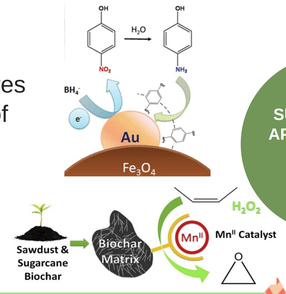
100% atom economy

Minimizes unwanted side reactions, leading to higher yields and less waste.

Research

- Bifunctional Au−Fe_3O_4 Heterostructures for Magnetically Recyclable Catalysis of Nitrophenol Reduction.[2]

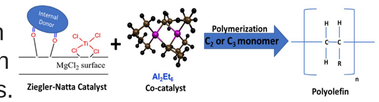
- Biochar as supporting material for heterogeneous Mn(II) catalysts[3]: Efficient olefins epoxidation with H_2O_2



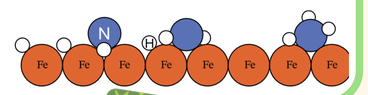
SUCCESSFUL APPLICATIONS

Industry

- Ziegler-Natta catalysts supported on $MgCl_2$ are widely used for production of polyethylene and other polyolefins.



- The Haber-Bosch process: NH_3 production from N_2 and H_2
  Iron catalyst is often support in Al_2O_3
  Second-generation Ru-based catalysts are used to operate under milder conditions



References: 1) Munnik, P., De Jongh, P. E., & De Jong, K. P., *Chem. Rev.* ***2015***, *115*(14), 6687-6718. 2) Lin, F. H., & Doong, R. A., *J. of Phys. Chem.* ***2011***, *115*(14), 6591-6598. 3) Pierri, L., Gemenetzi, A., Mavrogiorgou, A., Regitano, J. B., Deligiannakis, Y., & Louloudi, M. *Mol. Cat.* ***2020***, *489*, 110946.