A greener future: nanoparticle catalysis

Chemical manufacturing is big business, worth 4.5 trillion dollars worldwide. With this though comes an incredible environmental cost as such processing accounts for nearly half of all industrial electricity usage. Many waste manufacturing products are also dangerous pollutants in themselves. Thankfully, researchers in green chemistry, such as **Dr Audrey Moores** at McGill University, may have an answer to reducing the enormous environmental footprint of this industry through the innovative use of nanoparticles in chemical synthesis.

Chemical synthesis is a bit like cooking. Several starting chemicals are mixed together, maybe heated a little, and over time a new chemical product is formed. Industrial scale chemical manufacturing has many similarities, except that, for one reaction, there might be tons of chemical reagents and temperatures of hundreds of degrees required. All of this means that the chemical manufacturing industry consumes a huge amount of electricity and is a significant contributor to greenhouse gas emissions and, ultimately, global warming.

Given the economic value of chemical manufacturing (4.5 trillion dollars worldwide), there is a huge amount of interest in trying to make the synthesis processes faster, more energy efficient, with greater product yields. One approach to achieve this is to use a catalyst for the reaction: a reagent that, when added to the chemical making pot, increases the rate of reaction without being consumed by the reaction itself. Catalysts speed up reactions via many different mechanisms and some are even light-activated which can allow chemical reactions to be performed at lower temperatures. Catalysts are so powerful that virtually all products manufactured have at some points in their life experienced a catalysed transformation.

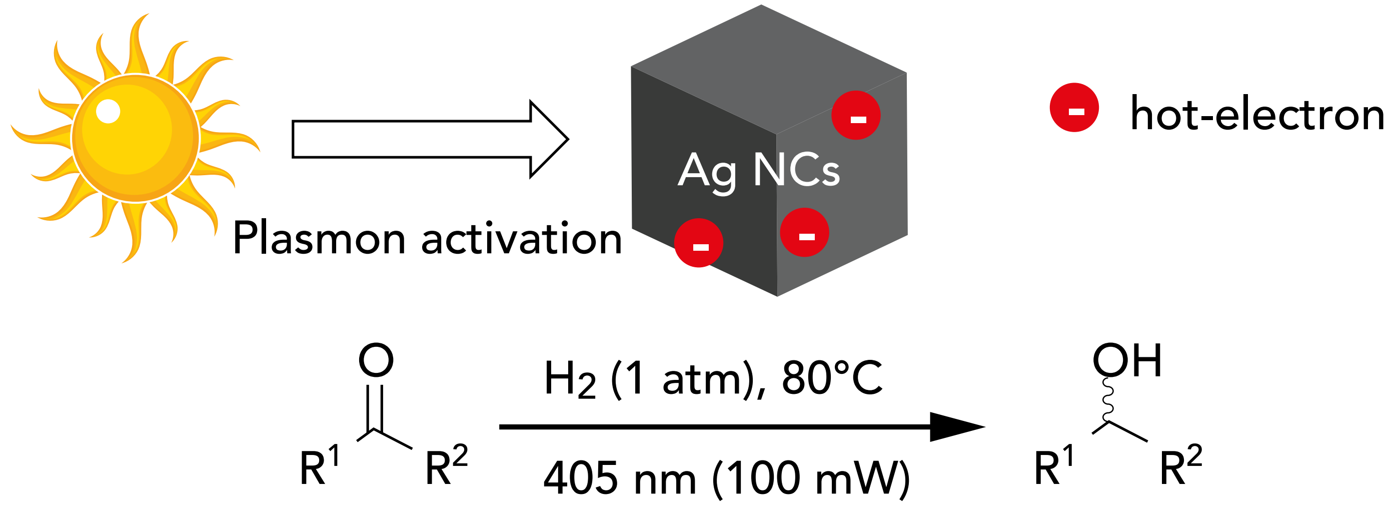
However, while catalysts can be found in the majority of industrial processes, they come with their own environmental problems. Some commonly used catalysts are based on metal-containing compounds. For example, palladium is commonly used as a catalyst for fine chemical synthesis, as well as being found in catalytic converters for car exhausts. It is, however, very toxic. It is commonly used in drug manufacture, but its toxicity imposes strict regulations and expensive cleaning procedures to get rid of any trace amount of metal from the synthetic process. Mining the palladium is another huge source of environmental damage and, as it is a relatively rare element with a growing number of applications, there are questions around whether the demand for palladium will subside in the near future.

Finding ways to clean up industrial processes is the speciality of Dr Audrey Moores at McGill University. Her research focuses on developing new, nanoparticle-based catalysts for chemical synthesis and also finding alternative, more environmentally-friendly ways of making the nanoparticles for these applications. For example, rather than using palladium catalysts, which can leach into the final product with toxic effects, she has found an alternative iron catalyst, that is not only cheaper, but poses none of the same toxicity risks.

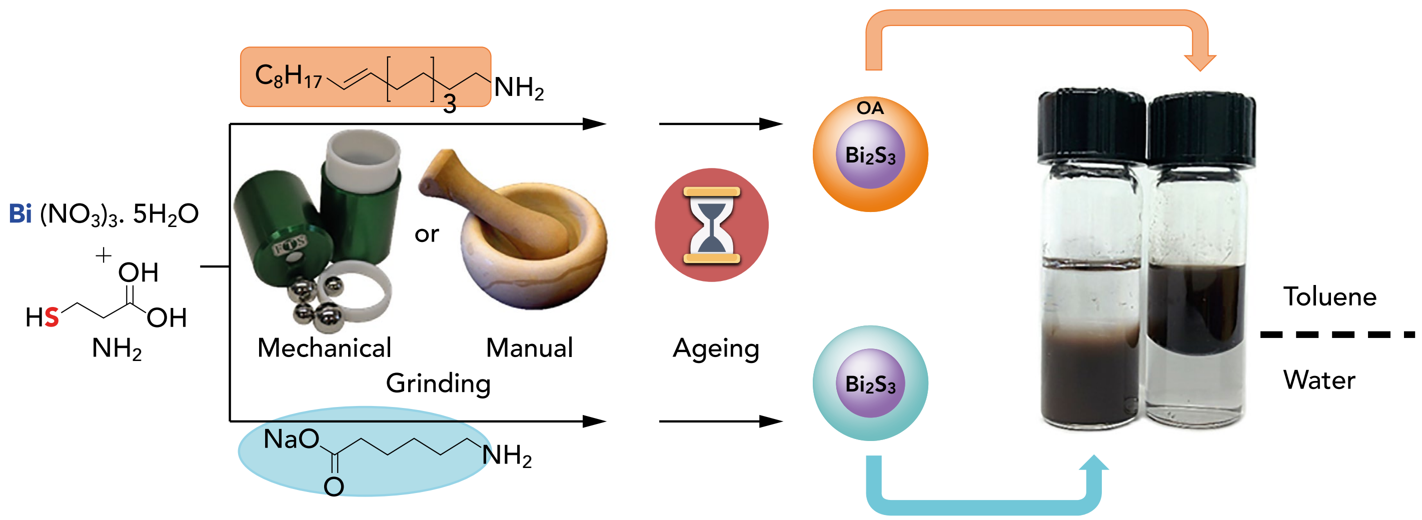
NANO-SCALE CATALYSIS

A nanoparticle is a name given to any particle that has a diameter between one and a hundred nanometres, a similar size to a small virus. Nanoparticles have a range of applications and are found everywhere from stain-repellents for furniture to cancer treatments. While their name might be easy enough to understand, the chemical constituents and construction of the particle is often very complex. For example, a gold-based nanoparticle has a gold core but is surrounded by layers of surface groups that determine the overall shape of the particle.

While catalysts can be found in the majority of industrial processes, they come with their own environmental problems



Silver nanocubes allow researchers to harvest light and use it in catalysis.



Mechanochemistry was used to simply, and without additional solvent, access small nanoparticles of bismuth sulfide.

Despite the excitement surrounding their applications, many nanoparticles are challenging to synthesise simply and in a scalable fashion. There is a strong link between the size and shape of the particle and its behaviour, so it is important to not only have the correct chemical ingredients but to control its dimensional properties too. Historically, this has been achieved through processing techniques involving large chemicals excess or high temperature plasma (>1000 °C).

To address this point, Dr Moores has been making use of mechanochemistry, a recently emerging field of chemistry, whereby energy is delivered to the reactive medium in the form of mechanical force. This allows the synthesis of nanoparticles in a process with greatly reduced energy and solvent requirements. In the solid phase, reagents are mixed and energy is delivered in the form of shearing forces. Surprisingly, nanoparticles can nucleate in such an environment, with remarkable size and growth control, affording systems typically smaller than what is achieved in solution.

Dr Moores and her group have been able to apply this with great success to the synthesis of ultra-small gold nanoparticles and bismuth sulfide nanoparticles, which are used as a contrast agent in cancer detection. As well as the environmental advantages, this is also a cheaper synthetic method that allows bulk synthesis of the nanoparticles. The group have also applied these techniques to use lignin, a waste product of the forestry industry, and silver, to make antibacterial filters that can kill up to five kinds of bacteria, including antibiotic resistant strains.

Dr Moores' research is of great importance to a wealth of different chemical sectors

LIGHT-ACTIVATED CATALYSTS

Another substitution approach to heating chemical reactions is to try and supply this energy in the form of light. Light-initiated chemical reactions are known as photochemical reactions and certain catalysts can also be triggered in a similar way. Dr Moores has been making use of the very special optical properties of nanoparticles to make photocatalytic nanoparticles that can be used for highly selective chemical synthesis. This means it is possible to selectively perform chemical reactions on only the desired parts of the molecule, a very important property in fine chemical synthesis.

Dr Moores has been using silver nanoparticles that absorb visible light very strongly to perform some of the chemical reactions that are of great interest to the perfume industry in the first example of a reaction of this type. Finding selective catalysts that behave in this way is challenging in itself so an effective, green alternative that can be performed with relatively simple nanoparticles is a highly appealing prospect.

A GREEN FUTURE?

With the developments of both new methods for the creation of nanoparticles and novel applications to chemically challenging problems, Dr Moores' research is of great importance to a wealth of different chemical sectors. Given Dr Moores' active involvement in many programmes for green chemistry education, development and communication, there is a real hope that the technologies and the desire will be there to truly clean up chemical manufacturing in the future.

Q&A

How can chemical industries be encouraged to adopt these new, greener synthetic processes?

In the history of chemistry, there are many examples of industries adopting greener alternatives as a consequence of their being more economical, or in order to mitigate eco taxes or regulations. Yet it is true that the urgency of the current situation, in terms of pollution, global warming and scarcity of resources, calls for dynamic actions. Change in industry takes time because of capital cost. Governments have to play their role by producing creative eco taxes and responsibilities: metrics need to be better used to help consumers inform their choices.

How widely used do you think mechanochemistry could be for chemical synthesis?

Well, mechanochemistry is used a lot already, for instance in drug manufacture to access desirable formulation of active ingredients with excipients. What is taking place now is the realisation that some traditional organic and inorganic methods do work very well in the solid state. A large number of articles have been published visiting these concepts. Interestingly, what has now been discovered is that for some reactions, the outcome is not the same whether you work in the solid or in the liquid phase, thus expanding the field of possibilities. Mechanochemistry has a number of advantages which will surely lead to industrial applications: less solvent used, less energy used and better adaptability to scale up.

Do you think your antibacterial filters could be one approach to overcoming antibiotic resistance?

Silver is indeed a way to kill antibiotic resistant strains. We have proven that in our work, but this has been known for some time. This mechanism is based on the release of silver ions locally, which are lethal for the bacteria. Hence nanoparticles are very effective because they allow us to release a large concentration locally. Our design allowed this high concentration to be combined with a very low overall release of silver. This kind of technology is well adapted for point of use filters, for instance in emergency situations. Unfortunately, this idea is not well adapted to treat patients infected by such strains.

What are the remaining obstacles to cleaner chemical synthesis?

Good question! The ideal reaction is one for which all reagent atoms end up in the product, where no solvent is used, with no energy input and where purification is very easy, if not unnecessary. In a way biology offers a nice example of green reactions, fulfilling many of these constraints. Yet it does generate quite a bit of waste and calls for the use of complex and not always stable catalysts. These hurdles are being overcome right now and bioprocesses are definitely on the way. Organic and inorganic reactions now offer a large array of answers to address this question. I believe the challenge will really be the effective development of these methods for large-scale application.

Detail

RESEARCH OBJECTIVES

Dr Moores works in the area of 'green chemistry'. By developing novel processes using nanoparticles, she aims to reduce the amount of material and energy required to get to a specific end product.

FUNDING

Dr Moores thanks the Natural Science and Engineering Research Council of Canada (NSERC), the Canada Foundation for Innovation (CFI), the Canada Research Chairs (CRC), the Fonds de Recherche du Québec – Nature et Technologies (FRQNT), the Centre for Green Chemistry and Catalysis (CGCC), and McGill University for their financial support.

COLLABORATORS

Collaborators: Tomislav Friscic (Chemistry, McGill), C. J. Li (Chemistry, McGill), Christopher Barrett (Chemistry, McGill), J. Matt Kinsella (Bioengineering, McGill), Yasuhiro Uozumi (RIKEN, Japan), Yoichi Yamada (RIKEN, Japan), Nadi Braidy (Chem. Bio. Eng., U. Sherbrooke).
Students: Monika Rak, Michael Landry, Michael Malca, Huizhi Bao, Reuben Hudson, Alexandra Gellé.

BIO

Audrey Moores is an Associate Professor of Chemistry at McGill University. She was awarded a Tier II Canada Research Chair in Green Chemistry which ended in 2017. Dr Moores completed her PhD from the Ecole Polytechnique, France in 2005, under the supervision of Prof. Pascal Le Floch. She was a post-doctoral fellow at Yale University in 2006 under the guidance of Prof. Robert H. Crabtree.

CONTACT

Dr Audrey Moores,
Associate Professor
Office 310 Otto Maass Chemistry Building
Department of Chemistry
McGill University
801 Sherbrooke St. West
Montreal, QC,
Canada H3A-0B8

E: audrey.moores@mcgill.ca
T: +1 438 884 2135
W: www.mcgill.ca/moores-group/
https://twitter.com/pivotbio