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Amazing microdroplet structures may lead to new technologies

Unexpected shapes of mesoscale atoms – structures built of microdroplets encapsulated within microdroplets – have been created at the Institute of Physical Chemistry of the Polish Academy of Sciences in Warsaw, Poland. The discovery was possible with a new method for precise control over placement of tiny segments of liquid, one in another. With further progress in innovative microfluidic systems, the method may find use in medicine and materials science.

In the prestigious physics journal "Physical Review Letters" a team of researchers from the Institute of Physical Chemistry of the Polish Academy of Sciences (IPC PAS) in Warsaw, Poland, have unveiled a new method of controlling the shapes of structures – so called mesoatoms – formed by microdroplets placed inside another drop. The work increases the possibilities of controlling the processes of self-organization of matter. During their research, the scientists also managed for the first time to observe the formation of microdroplet structures with unexpected shapes.

It has long been known that it is possible to place inside the drop of one liquid a certain number of droplets of another immiscible liquid. It is also known that under certain conditions the internal droplets can arrange themselves into stable structures. Until now, however, it was assumed that the shapes of these structures depended only on the number of droplets forming them. As a result, the number of different structures of mesoscale atoms it was possible to obtain was very limited.

"We have shown that the shapes of the structures that spontaneously arrange themselves inside the drops depend not only on their number, but also on the relative proportions of their volume. The existence of the second parameter significantly enhances the ability to form new mesoscale atoms. As a result, we now have at our disposal a spontaneous process with a rich potential, and one that we can to an extent control," says Prof. Piotr Garstecki (IPC PAS).

Stable structures of droplets within drops are produced at IPC PAS with the help of microfluidic systems. Systems of this type are typically formed by two plates of plastic. A network of carefully designed grooves is applied to one plate and the second fulfils the role of the 'lid'. After securing the two plates together the grooves become channels with sub-millimeter diameters, filled with a carrier fluid. If small portions of working fluid, immiscible with the carrier fluid, are injected into the microchannels, droplets form. The techniques developed at IPC PAS make it possible to precisely control the motion of multiple tiny segments of liquids.

“In the course of our research we injected equal, small portions of dyed water, one straight after another, into a channel filled with oil. Since oil is immiscible with water, a 'string' was created of a number of blue, virtually identical, microdroplets. Interesting things started to happen when such a droplet 'train', flowing in oil of one type, was injected into a channel filled with another oil immiscible with the other two fluids,” says Dr. Jan Guzowski (IPC PAS; currently at Princeton University).

The surface tension of the liquid shell around the encapsulated droplets caused it to itself form a drop. During this process, the encapsulated microdroplets were subjected to considerable forces, became deformed, and organized in order to minimize the energy of the surface constraining them. Depending on the configuration – the number of droplets within the drop and the ratio between the volumes of all the droplets – a unique structure of a mesoscale atom formed. The researchers could observe a number of distinct geometries of the atoms. A real surprise was that they could also observe structures containing all core droplets arranged in a row, one after another, just like peas in a pod.

“The configuration wherein a few droplets form a row only seems to be unstable. Our calculations show that in order to stick together in a cluster, the aligned droplets would have to undergo deformation 'on the way' requiring an input of additional energy. The flow carrying the droplets is not strong enough for this and as a result the droplets remain frozen in the original arrangement. Finally, the whole structure looks like a group of several tennis balls pushed one the after the other into a tight shirt sleeve,” says Dr. Guzowski and emphasizes that the existence of capillary barriers, preventing the spontaneous reconfiguration of the structure of microdroplets, has been presented for the first time.

The mesoscale atoms of droplets within drops obtained by the team from IPC PAS had just sub-millimeter dimensions, and were thus relatively large.

“Laboratory experiments are easier to perform on larger drops and in a manner that permits their easy observation,” explains Prof. Garstecki and points out: “There are, however, no fundamental obstacles to reducing the droplet size by one or two orders of magnitude. The capillary forces that are responsible for the formation of structures are even stronger at small scales. We expect, therefore, that the process should be faster, and even more controllable when targeting sizes significantly below the millimeter scale.”

The controlled production of mesoscale atoms from droplets is of particular importance for materials science. This is because materials come into being in a manner somewhat similar to structures made of building blocks: they are 'made up' of many smaller 'bricks' – tightly packed clusters of particles or atoms. A promising area of use seems to be the transport of drugs to specific areas of the body. Each drop in the mesoscale atom could contain various therapeutic substances which would be released under different conditions. This sort of 'smart' container for medicines could carry out carefully planned drug therapy in a selected organ in the human body.

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The Institute of Physical Chemistry of the Polish Academy of Sciences (http://www.ichf.edu.pl/) was established in 1955 as one of the first chemical institutes of the PAS. The Institute's scientific profile is strongly related to the newest global trends in the development of physical chemistry and chemical physics. Scientific research is conducted in nine scientific departments. CHEMIPAN R&D Laboratories, operating as part of the Institute, implement, produce and commercialise specialist chemicals to be used, in particular, in agriculture and pharmaceutical industry. The Institute publishes approximately 200 original research papers annually.

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LINKS:

http://www.ichf.edu.pl/
The website of the Institute of Physical Chemistry of the Polish Academy of Sciences.

http://www.ichf.edu.pl/press/
Press releases of the Institute of Physical Chemistry of the Polish Academy of Sciences.

SCIENTIFIC PAPERS:

”Droplet Clusters: Exploring the Phase Space of Soft Mesoscale Atoms"; J. Guzowski, P. Garstecki; Physical Review Letters 114, 188302 (2015); DOI: http://dx.doi.org/10.1103/PhysRevLett.114.188302

IMAGES:

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Mesoscale atoms (structures formed by microdroplets of water trapped in a drop of oil) produced at the Institute of Physical Chemistry of the Polish Academy of Sciences in Warsaw, Poland. (Source: IPC PAS)