The mysterious 'action at a distance' between liquid containers

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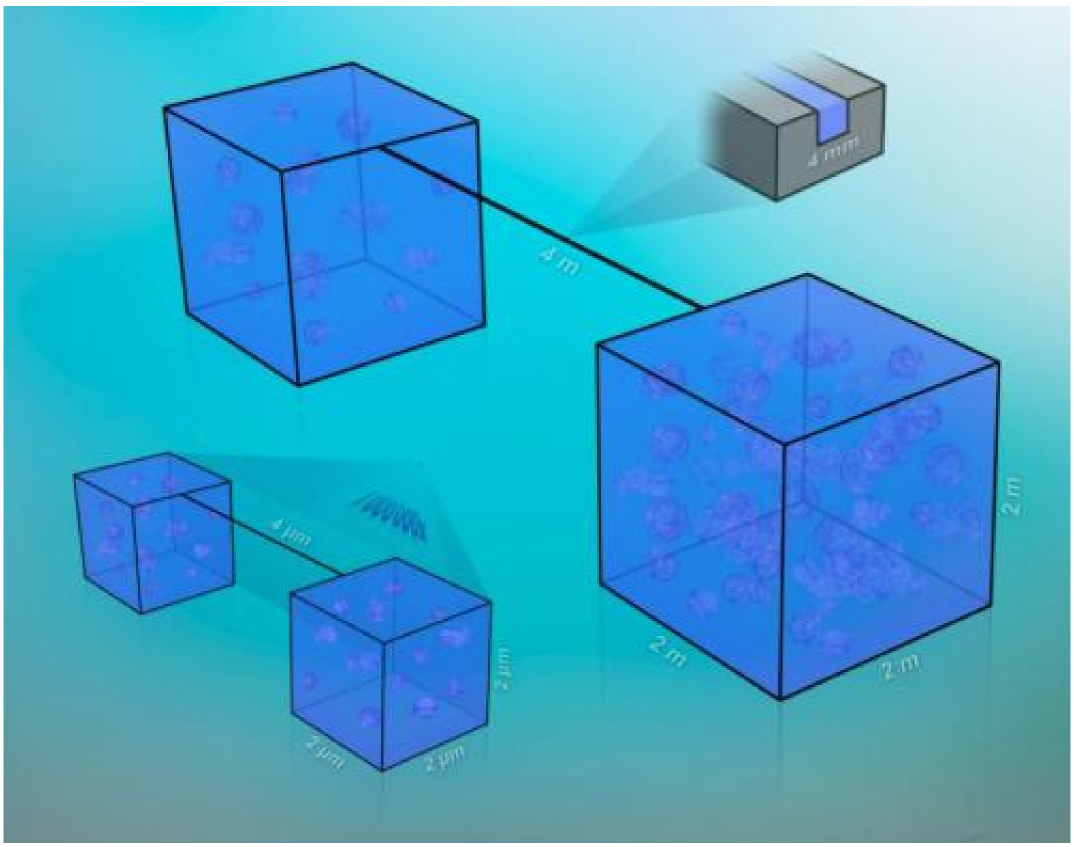

When large reservoirs are connected by very narrow and long channels, the liquid in each reservoir acts independently of the liquid in adjacent reservoirs. In the microworld, the physics is different: if the liquid filling the reservoirs complies with certain conditions (the most important of which is that the fluid is at coexistence between its two phases), even surprisingly small channels can correlate the state of the liquid in adjacent reservoirs. Credit: IPC PAS

For several years, it has been known that superfluid helium housed in reservoirs located next to each other acts collectively, even when the channels connecting the reservoirs are too narrow and too long to allow for substantial flow. A new theoretical model reveals that the phenomenon of mysterious communication "at a distance" between fluid reservoirs is much more common than previously thought.

Liquids in containers that are at a distance from each other may behave collectively, even if the channels connecting the reservoirs are so narrow and long that they prevent significant flow. The mysterious "action at a distance" was discovered only recently and was only observed in helium cooled to a very low temperature. The theoretical model of the phenomenon, developed by an international team of scientists, including those from the Institute of Physical Chemistry of the Polish Academy of Sciences (IPC PAS) in Warsaw, however, suggests that this effect may also be present in other liquids - and in much more typical conditions.

The first report of the "action at a distance" between reservoirs of liquid was published in 2010 in *Nature Physics*. The team from the University at Buffalo and the State University of New York created an array of tens of millions of hollows for liquid helium on a silicon plate. Each small reservoir was a cube with an edge of two microns (millionths of a metre), and the centres of adjacent reservoirs were six microns apart. The prepared plate was covered with another full silicon plate. This was done so as to leave a very narrow gap above the reservoirs, of only 32 nanometres (billionths of a metre). The gap enabled all the reservoirs to be filled with liquid helium.

The size of the gap was thousands of times smaller than both the size of the reservoirs themselves and the distance between adjacent reservoirs. Such compact dimensions made significant flow virtually impossible. It was thus expected that after pouring in liquid helium it would "do its own thing" in each reservoir, regardless of what was happening in adjacent reservoirs. In the experiment, the specific heat of the liquid helium was measured in a single reservoir, and in the entire system. If the reservoirs were truly independent, the specific heat of the whole system would equal the specific heat of a single reservoir multiplied by the total number of reservoirs. However, this was not the case: a clear excess of specific heat was observed in the system. The superfluid helium, apparently divided into millions of independent reservoirs, was inexplicably acting as if it was still a physical whole.

"Let's change the scale for a moment and imagine cubic containers, each with a side of two metres. Each pair of containers is connected by a tube four metres long with a diameter of three millimetres. According to existing theories, such a small channel should not synchronize the phenomena occurring in the containers. And yet, in the microworld it does!," says Dr. Anna Maciołek of IPC PAS, the Max-Planck-Institut für Intelligente Systeme and the University of Stuttgart.

Superfluid helium is a liquid whose properties are to a large extent the result of quantum phenomena, so initially it seemed that it was those that were responsible for the outcome of the experiment. In cooperation with Prof. Douglas Abraham from Oxford University, Dr. Maciołek has developed a theory describing the observed phenomenon. The new theory, confirmed by computer simulations carried out by Oleg Vasilyev from the Max-Planck-Institut für Intelligente Systeme, proves that the effect of "action at a distance" does not require quantum physics and can also occur in classical one-component fluids, as well as in mixtures.

Analysis of the new theoretical model has revealed that the phenomenon occurs under certain conditions. For it to occur, in the initial experiment the liquid helium needed to be at a state close to the appearance (or disappearance) of superfluidity. For other fluids, however, low temperatures are not required. Water and lutidine - a model mixture of water with oil - mix only in a certain range of temperatures and "action at a distance" only appears within this range. The most important requirement therefore turns out to be the proximity of the phase transition, that is, the state in which the two different forms (phases) of the liquid can occur simultaneously. The dimensions of the reservoirs and the connecting channels are also important: the phenomenon ceases to exist when the distances are significantly larger than the size of human cells.

"Physics in the microworld, even classical physics, is turning out, not for the first time, to be different from the physics we all know from everyday life," concludes Dr. Maciołek.

The results, presented recently in the pages of the well-known physics journal *Physical Review Letters*, can be applied, among others, in microfluidic systems. Systems of this type are constructed to carry out chemical or biological experiments on individual droplets. The sizes of the containers and channels in microfluidic systems are so small that the "action at a distance" described here can then occur - as an unintended effect, disturbing the results of experiments, or as an intentionally introduced factor increasing the functionality of the system.

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