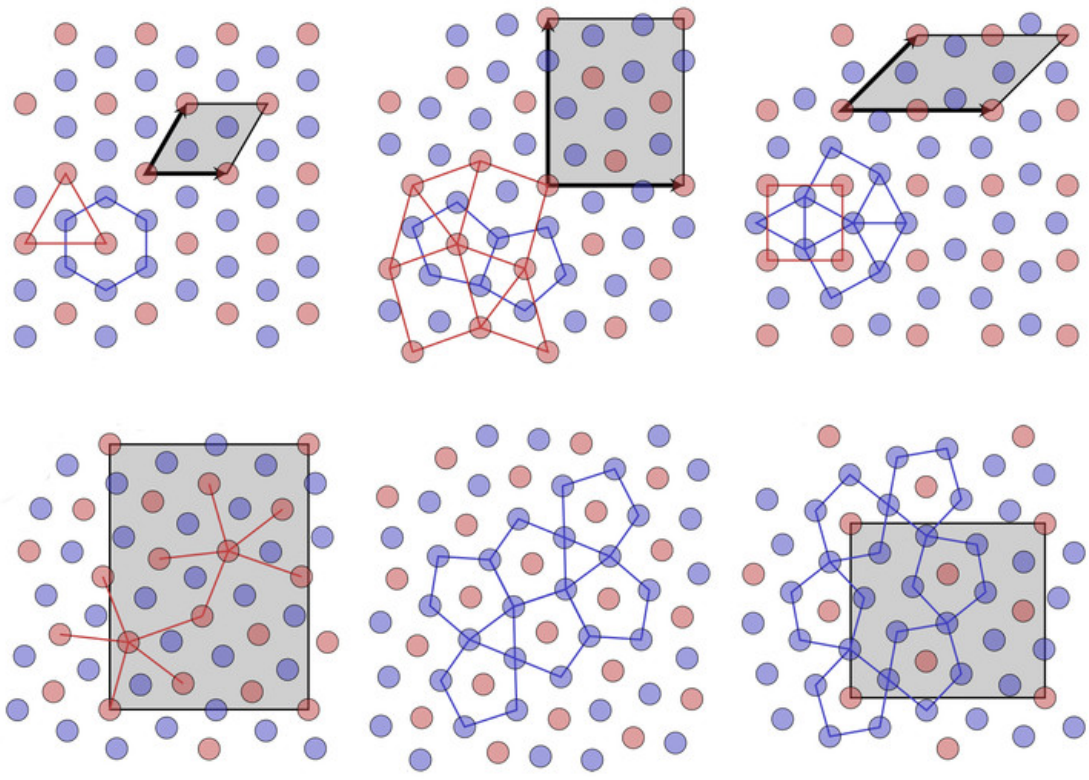
Artificial 2-D crystals modified at the touch of a button

September 30 2016



Very different structures can emerge when particles are kept between two charged plates. Credit: Vienna University of Technology

Charged particles can form via self-organization processes an unexpectedly large range of crystal structures entirely by themselves. A research team with participants from TU Wien has demonstrated how easily the formation of these structures can be controlled via external parameters.

A huge and colourful variety of crystals can be found in nature – from simple salt crystals to iridescent opals and biological crystals that are responsible for the glorious colouring on butterflies' wings. New technological methods have made it possible to expand the range of crystals even further. 'Colloidal systems' often consist of particles that are able to form ordered structures entirely by themselves via so-called self-organization. A research team with participants from TU Wien has now demonstrated that you can make particles that form an astonishingly large number of completely different crystal structures between two charged plates. Slight changes in the distance between these plates or their electrical charge causes the particles to form a completely different pattern.

Wigner crystals

The basic idea has been around for a long time. "Eugene Wigner, a Nobel Prize winner and one of the leading personalities in theoretical physics, was investigating the spatial distribution of electrons in a two or three dimensional metal as early as the 1930s," explains Prof. Gerhard Kahl from the Institute of Theoretical Physics at TU Wien. "They do not form a random pattern but create a structure, known as a Wigner crystal." Wigner's prediction that the particles form in two dimensions a hexagonal lattice was successfully confirmed only in 1979 depositing electrons on a helium surface.

The obvious next step was to investigate the behaviour of particles between two parallel charged plates. Moritz Antlagner devoted part of

his thesis to this question in Gerhard Kahl's research group. It soon became obvious that he touched a very delicate problem: the particles are able to self-organize under these conditions in a remarkably broad spectrum of different ordered structures. Triangular, quadrangular and even pentagonal patterns are found. The latter are particularly unusual in ordered structures and might indicate the possible emergence of quasicrystals. Even various combinations of these patterns are found. The particles can arrange themselves in two layers: one at the upper plate and the other at the lower plate. Each layer can form its own geometric pattern. The overall structure is only stable if the two patterns are compatible and have a suitable geometric relationship with one another.

The task of identifying and characterising the stability range of possible patterns was extremely demanding: "We performed analytical calculations and developed suitable computer simulations and special new types of optimisation algorithms," says Gerhard Kahl. In their activities the Viennese team was reinforced by colleagues from Paris and Bratislava. An enormous amount of computational resources was required: "We needed around 1.5 million CPU hours on mainframe computers in Vienna and Paris. We also had to dedicate a lot of work to analysing and interpreting the data," reports Gerhard Kahl. With a great deal of patience and perseverance, the team was finally able to classify the huge number of possible structures in the form of a diagram, known as a phase diagram.

The investigation showed that the amazing variety of crystal patterns between the two plates depends on just two characteristic variables: the distance between the plates and the asymmetry of the charges of the plates. Different combinations of these two parameters can lead to completely different ordered patterns.

"We were surprised by how easily the emergence of possible structures can be controlled – using a combination of just two parameters," says

Gerhard Kahl. This means that two-dimensional crystal structures can now be selectively controlled and changed at the touch of a button. "This may have great significance for the physics of bilayer semiconductors, ionic plasma and bilayer graphene," says Kahl.

Provided by Vienna University of Technology