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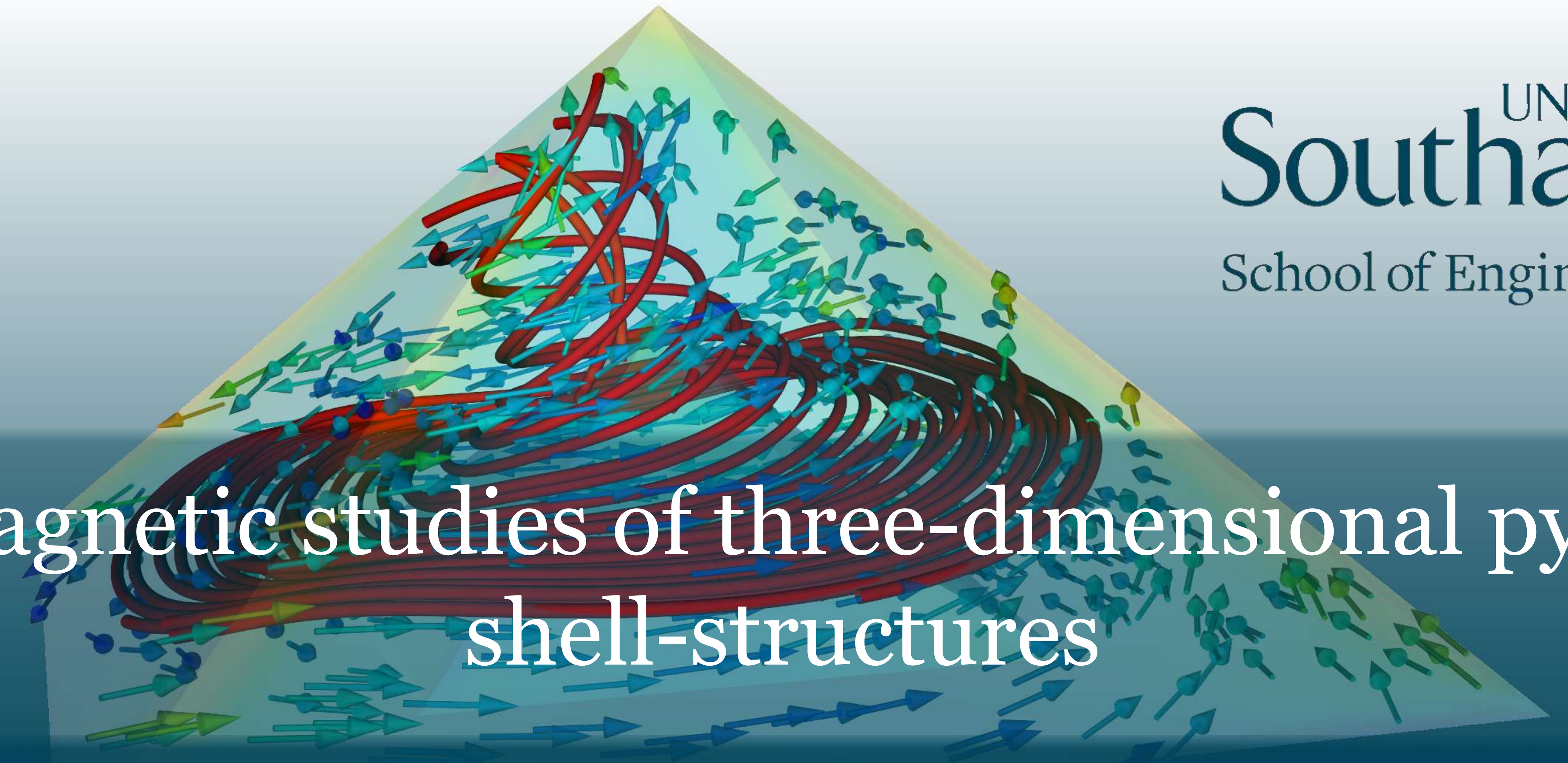

Micromagnetic studies of three-dimensional pyramidal shell-structures

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Introduction to magnetism

The interaction between two magnets can be described by the assumption that each magnet comprises two poles, a plus and a minus pole. Bringing together two magnets in such a way, that the plus pole of the one magnet faces the minus pole of the other one, will result in an attractive force between them. By contrast, they will repel each other if one brings together the two minus poles (or equivalently, plus poles). The magnetic properties of matter are (mainly) due to electrons which, as they have an electric charge and an intrinsic magnetic moment, act as small magnetic dipoles. While strictly speaking every material is magnetic, only ferromagnetic materials (for example Iron, Cobalt, Nickel) exhibit magnetic properties in the absence of an externally applied magnetic field. Ferromagnetic materials are the subject of our research. This poster presents our work on the magnetic properties of ferromagnetic, pyramidal-shaped core-shell structures, which consist of an only weakly magnetic pyramid (the core, here made of silver), which is covered by a ferromagnetic layer (the shell, here made of Nickel). These structures (figure 1) are grown by our collaborators at the University of Bath using a novel growth method based on electrodeposition. Here, we will concentrate on numerical investigations of these structure, for which we use the micromagnetic model. The simulated structures are currently about one order of magnitude smaller than grown structures.

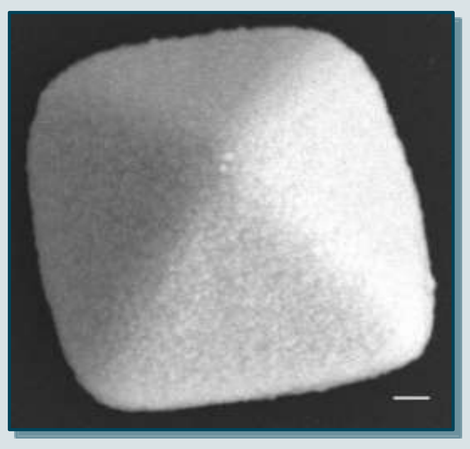

Figure 1: Atomic force microscope image of a core-shell structure with a silver (Ag) core and a Nickel shell. The scale bar corresponds to 1 micrometer.

The micromagnetic model

We treat magnetism on a mesoscopic scale, i.e. we spatially average the microscopic magnetic moments over a microscopically large, but macroscopically small volume. The resulting, averaged quantity is a vector field, the magnetisation M(r). The magnetic state of the system is fully described by M(r). The standard micromagnetic model is usually used to compute for M(r) ferromagnetic structures. It defines four energy terms, each exerting a local torque on M(r). In figure 2 we discuss each term by adding it (from left to right) to a ferromagnetic cylinder system.

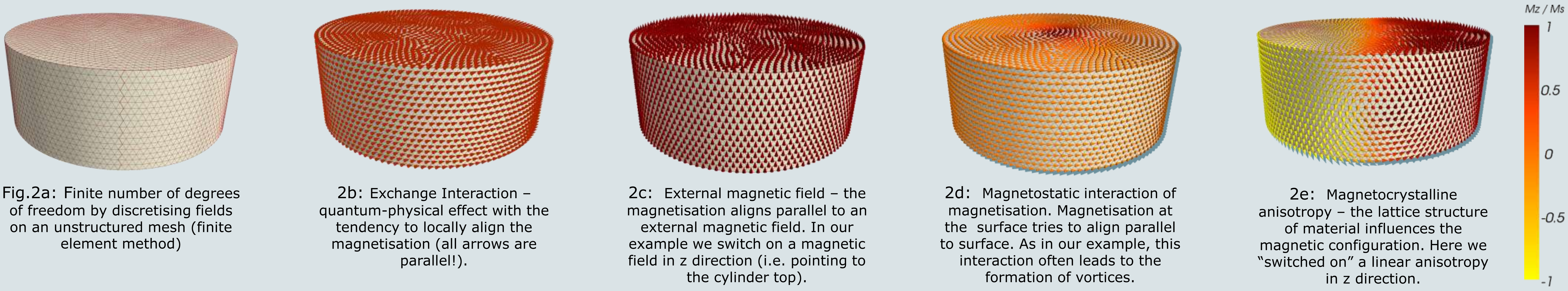

Fig.2a: Finite number of degrees of freedom by discretising fields on an unstructured mesh (finite element method)

2b: Exchange Interaction – quantum-physical effect with the tendency to locally align the magnetisation (all arrows are parallel!).

2c: External magnetic field – the magnetisation aligns parallel to an external magnetic field. In our example we switch on a magnetic field in z direction (i.e. pointing to the cylinder top).

2d: Magnetostatic interaction of magnetisation. Magnetisation at the surface tries to align parallel to surface. As in our example, this interaction often leads to the formation of vortices.

2e: Magnetocrystalline anisotropy – the lattice structure of material influences the magnetic configuration. Here we "switched on" a linear anisotropy in z direction.

Ferromagnetic configurations in pyramid-shaped systems

The magnetic properties of ferromagnetic nanostructures are strongly shape and size dependent, This provides the opportunity for the shape-controlled engineering of magnetic properties. Our work on magnetic core shell structures has to be seen in this context. Varying the geometry (figure 3) we find different stable, micromagnetic states (see figure 4 and 5). The most interesting configuration is the asymmetric vortex state, which comprises a vortex with a core sitting on one of the side faces (see figure 4). The displaced core of the asymmetric vortex state can be moved to one of the three other side faces by applying a corresponding external magnetic field. This behaviour could be potentially useful in view of applications like storage devices or magnetic sensors.

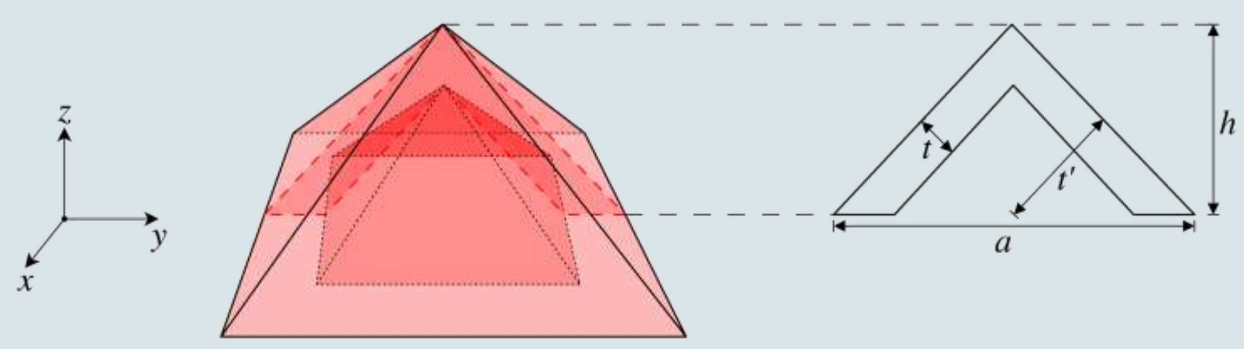

Figure 3: Sketch of the studied geometry. We consider two parameter: the side length a of the basal plane determines the size of our geometry. The relative thickness t_{rel}= 100.0 · t / t' is a shape parameter . The height h is set to a/2. The magnetic properties of the core are assumed to be negligible, so that only the shell is considered by the model.

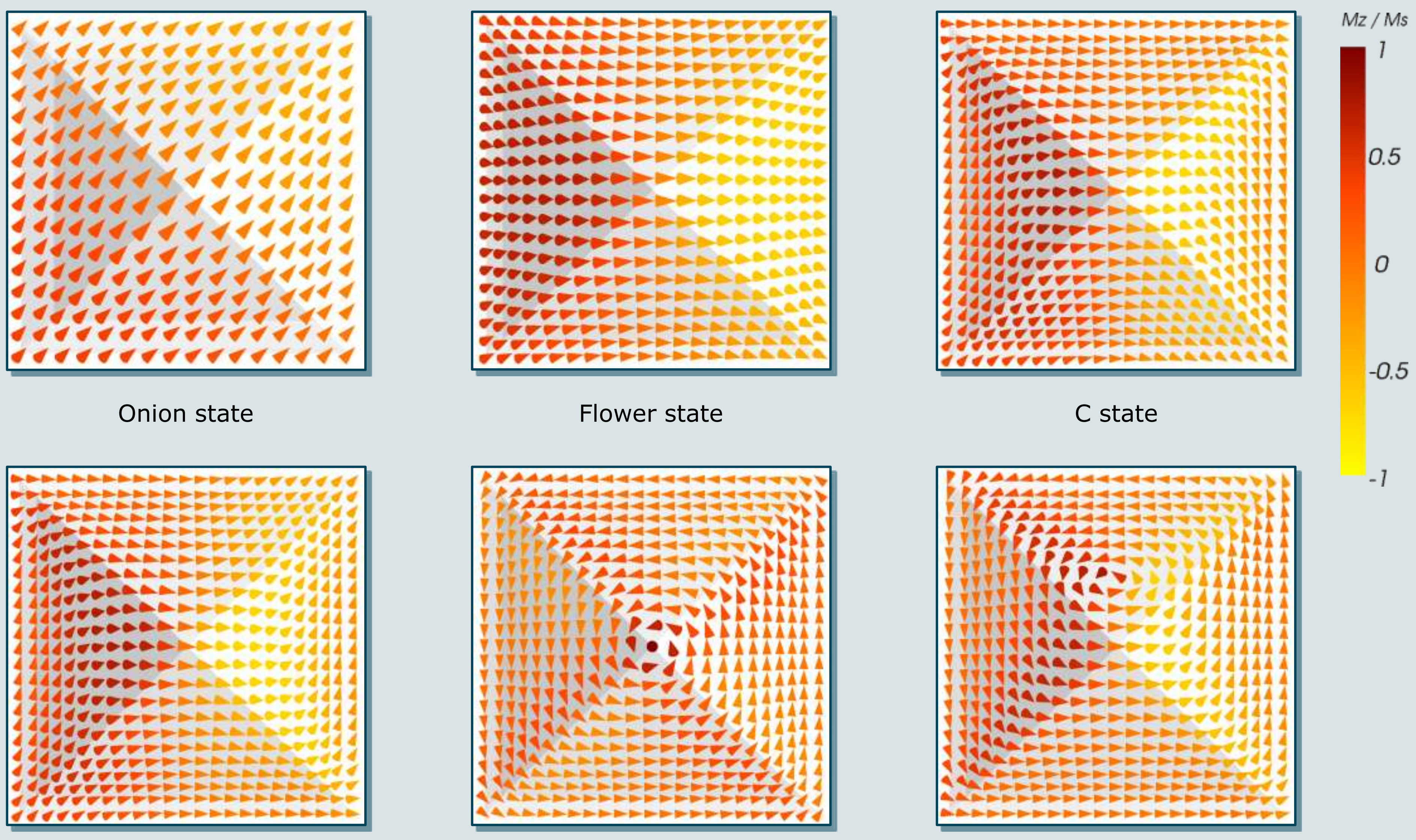

Figure 4: Illustration of observed micromagnetic configurations. The pyramidal structures are viewed from the top (the z direction of figure 3). The z component of the (normalised) magnetisation is denoted by the color bar. The names of the states derive from their appearance, e.g. the C state has its name as it resembles the letter C rotated 90 degrees clock wise. Only the S state is no micromagnetic ground state.

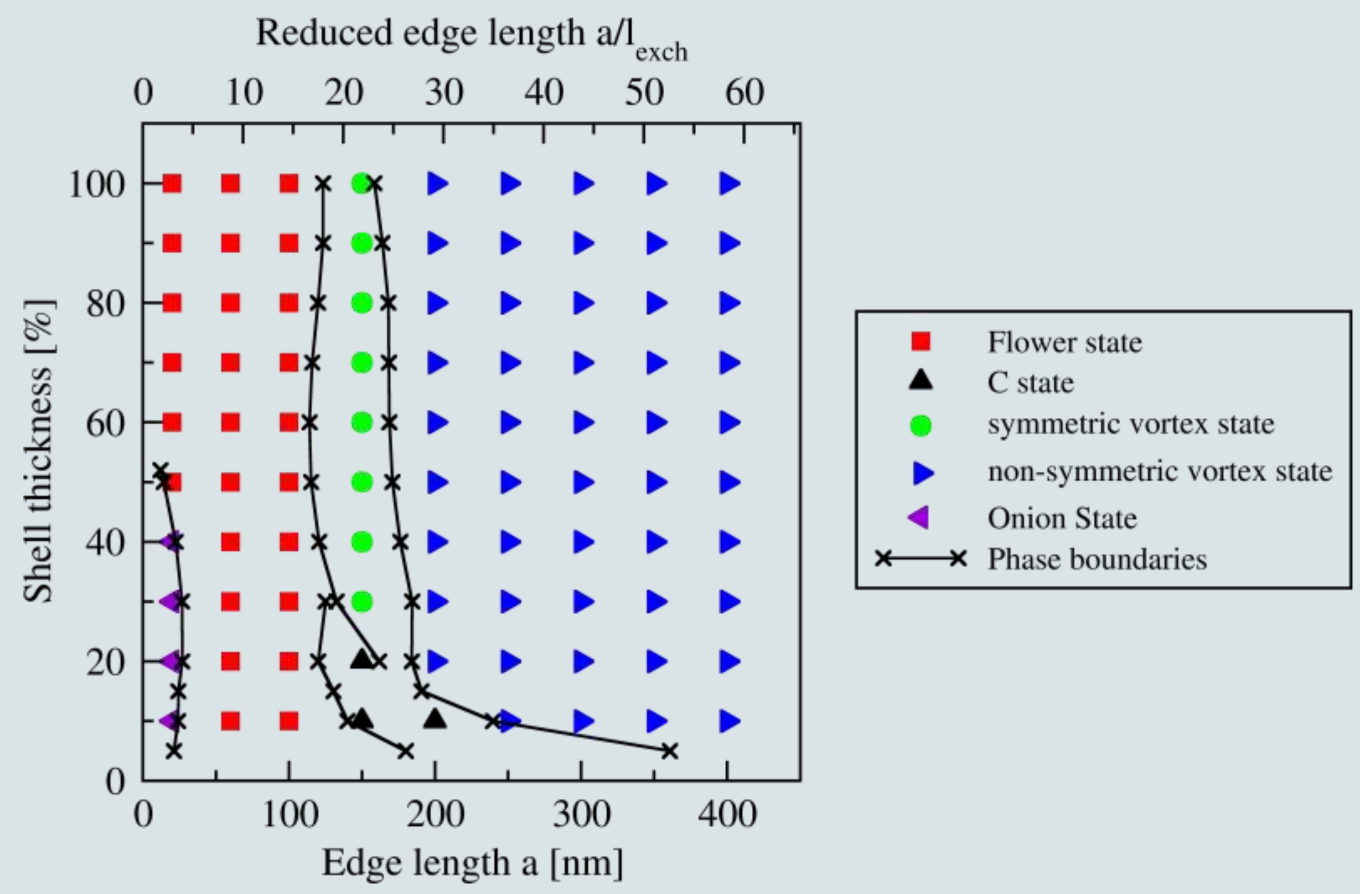

Figure 5: Phase diagram depicting the energetic ground state as a function of the two parameters a and t_{rel}. The shell thickness is varied between the limits of a infinitely thin shell and a solid pyramid. The ground state is the configuration with the lowest energy and, as such, is a stable configuration.

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