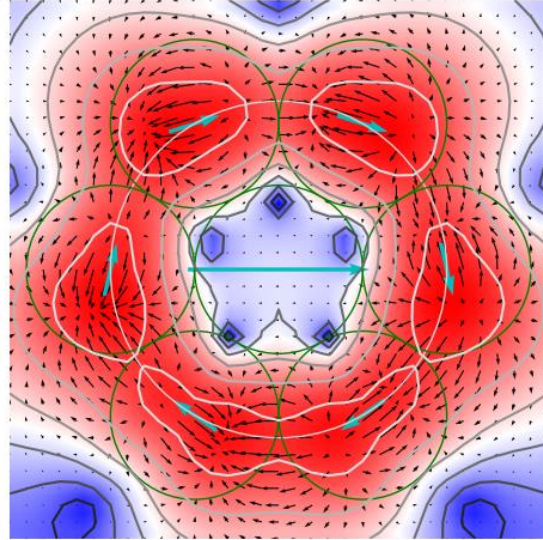


A hexagonal magnetic dipole cluster as a magnetic catastrophe machine.

(Version 1.2.2 of “animate_dipole_cluster.py”, February 2023)

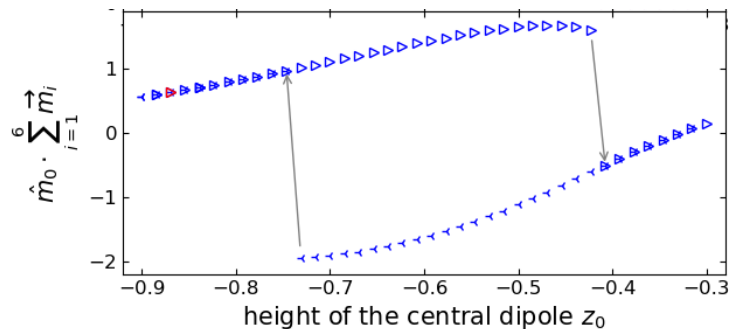


$\phi_3 = 17, \phi_4 = 76, \phi_5 = 145; U = -1.82; m_{\text{tor},z} = -5.90$



Details of the physics are described in <https://doi.org/10.48550/arXiv.2203.13670> or the corresponding [JMMM](#) article, and the references cited therein.

The Python code “animate_dipole_cluster.py”, current **Version 1.2.2**, is available here: [10.5281/zenodo.6380539](https://zenodo.org/record/6380539), or from the author Ingo.Rehberg@uni-bayreuth.de.



The animation makes use the numerical relaxation mechanism

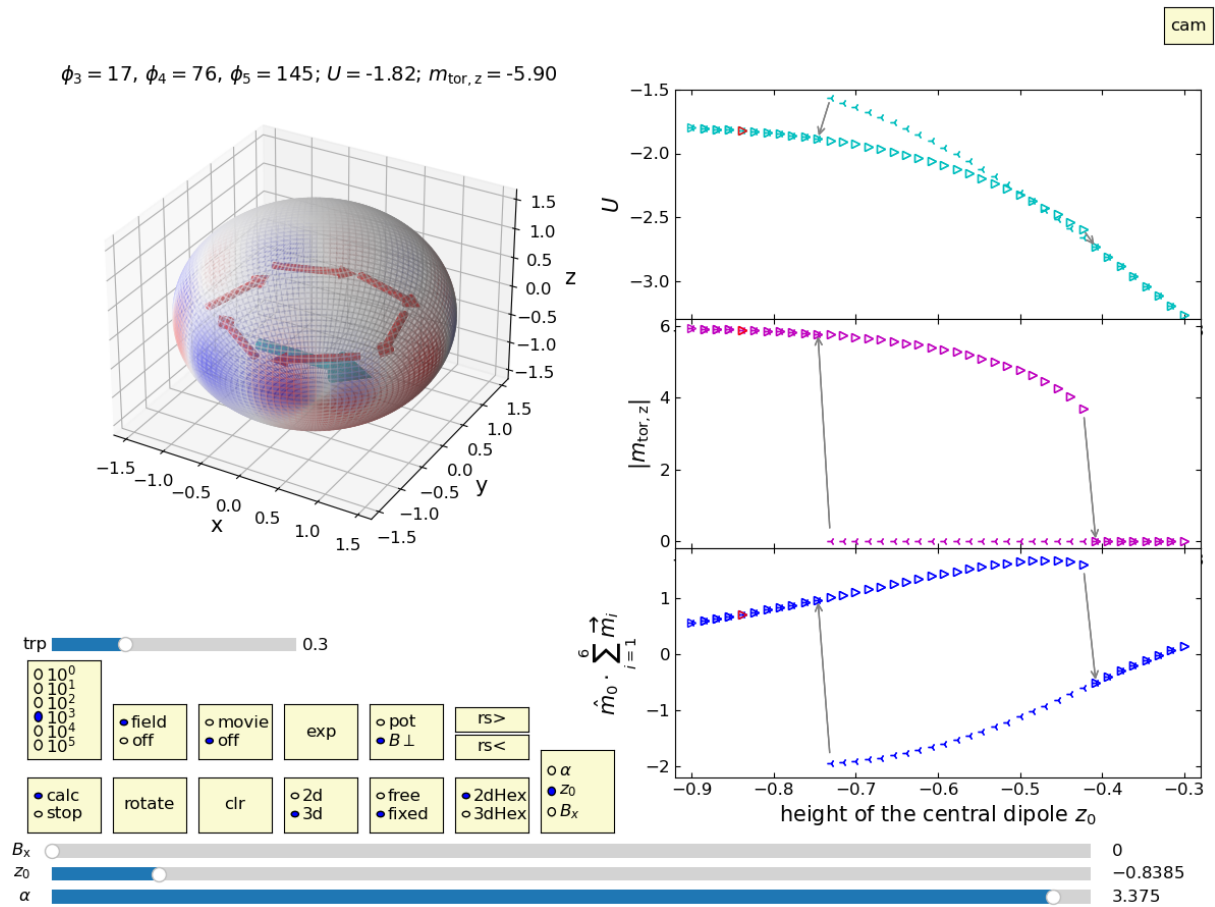
described in: [T. Friedrich, I. Rehberg, R. Richter, Comment on “Self-assembly of magnetic balls: From chains to tubes”, Phys. Rev. E 91 \(2015\) 057201](#).

In version 1.1 of the animation software, the strength of the central dipole moment acts as the control parameter. This version is restricted to two dimensions.

Version 1.2 adds the possibility to raise the central dipole out of the plane of the hexagon (it is thus a 3d-code, might be slower than the 2d-code of version 1.1, which is also available under this DOI).

In Version 1.2.1, an external B-field along the x-direction B_x acts as a third control parameter (a corresponding experiment would require additional coils). In addition, automatic, i.e. non-interactive, animation scenes can stored as an animated gif.

In Version 1.2.2 (February 2023), features are added to simulate the experiment where the height of the central dipole is adjusted by hand, while the 6 dipoles forming the ring are restricted to rotations in the plane, which is experimentally realized by means of nonmagnetic ball bearings. The experiment shall be presented in a forthcoming [talk](#). A movie of that handhold experiment is available with the files of version 1.2.2 under [10.5281/zenodo.6380539](https://zenodo.org/record/6380539). It can additionally be displayed within the animation.

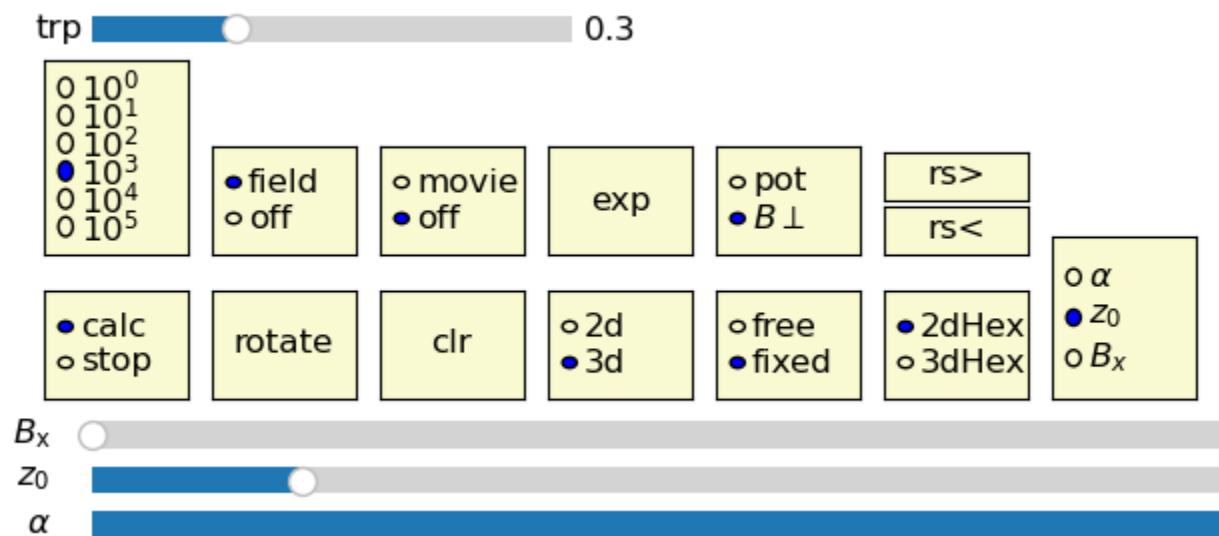


The **3d-figure on the left hand side** shows the seven dipoles in the filled hexagon configuration. The viewing angle can be manipulated with the mouse. The title shows three of the dipole angles (the other ones can be determined from those three due to the symmetry of the circular ground state), the magnetic potential energy U , and the toroidal moment $m_{\text{tor},z}$ of the present state.

The figures on the right hand side show from top to bottom

- i) the potential energy of the dipole-dipole interaction,
- ii) the z-component of the toroidal magnetic moment,
- iii) the dipole moment of the 6 dipoles forming the hexagon, projected along the direction of the centre dipole. When the centre dipole is allowed to rotate freely, its angle with respect to the z-axis is shown instead.

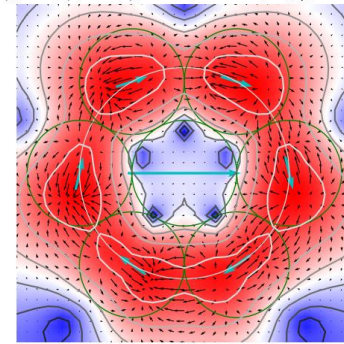
The sliders and buttons steer the interactive part of the animation:



- **α - slider**: Manipulates the strength of the central dipole, the bifurcation parameter.
- **z_0 - slider**: Manipulates the height of the central dipole, an alternative bifurcation parameter.
- **B_x -slider**: Manipulates the strength of an external homogenous field along the x-direction.
- **calc/stop radio button**: stop and restart the calculation.
- **rotate button**: Turns all dipoles in such a way that the angle ϕ_0 of the central dipole is within $\pm 30^\circ$ (This is always possible because of the 6-fold symmetry of this problem).
- **clr button**: erases the memory of the stored values for the 3 subplots on the right hand side.
- **2d/3d radio button**: Switches between 3d and a 2d (explained below) display of the configuration.
- **fixed/free radio button**: switch between a fixed orientation and a freely rotating mode of the central dipole moment.
- **2dHex/3dHex**: switch between an fixed orientation fixed to the xy-plane and a freely rotating mode of the six outer dipoles.
- **$\alpha/z_0/B_x$** : determines the control parameter displayed on the x-axis.
- **$10^0 \dots 10^5$ radio button**: the number of iteration between an update of the figure (beyond 1000 might take very long!).
- **field/off radio button**: Show additional fields or turn them off.
- **Movie/off radio button**: displays the hysteresis without manual interaction.
- **exp button**: starts showing a movie of the real experiment.
- **pot/ B_\perp radio button**: The field shown on the sphere can be the potential, or the component of the B field perpendicular to the sphere surface.
- **rs< button**: decreases the resolution of the "sphere".
- **rs> button**: increases the resolution of the "sphere".
- **trp-slider**: sets the transparency level of the sphere.
- **cam button**: starts showing the view of an external camera to display of the real experiment within a presentation.

For the 2d-representation with an active background one alternative button and two additional sliders are available:

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plane dist. 0.5

clip level 5.0

- **pot/B² radio button**: Switches between i) the potential and ii) the field energy density. This scalar field is shown on a plane above the planar hexagonal configuration. The vector field indicates the B_x, B_y field components.
- **plane dist. - slider**: determines the distance of the plane from the planar hexagonal configuration.
- **clip level - slider**: Can be used to manipulate the colour distribution of the background. The number denotes a multiple of the standard deviation of the scalar field.

An alternative experimental realization of this catastrophe machine is shown in the two photos.

