Interacting magnetic particles in soft elastic matrices:
mesoscopic modeling of magnetic gels and link to the macroscale

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Magnetic gels consist of magnetic or magnetizable colloidal particles embedded in a deformable elastic polymer matrix. If the elastic matrix is sufficiently soft, the magnetic interactions between the particles considerably affect the mechanical properties of the material. It is possible to modify the magnetic interactions from outside by external magnetic fields and thus to reversibly switch the mechanical features of the substances during operation.

We investigate such effects, using, for instance, reduced minimal dipole-spring models or more refined numerical simulations. In this way, we have analyzed the influence of the magnetic interactions on the static and dynamic elastic moduli and on the nonlinear stress-strain properties. We have found that anisotropic magnetic gels that contain chain-like aggregates of magnetic particles can show pronounced and switchable superelastic stress-strain behavior, i.e., an extended tunable plateau on the stress-strain curve. The underlying processes on the mesoscopic particle scale are readily identified. For the linear regime, we illustrate how a simple mesoscopic picture can help to heal shortcomings of conventional linear elasticity theory in the description of such anisotropic magnetic materials.

Recently, we have demonstrated how to effectively calculate analytically the coupled displacements of the magnetic particles in the elastic matrix. The particles are subject to, e.g., magnetic forces and torques. Mutual matrix-mediated interactions between the particles due to their deformation of the surrounding elastic medium need to be taken into account. The theory is verified by experimental results.