Size, shape, and orientation matter for nanoparticle uptake by wrapping

Sabyasachi Dasgupta, Thorsten Auth, and Gerhard Gompper

Forschungszentrum Jülich, Institute of Complex Systems and Institute for Advanced Simulation, 52425 Jülich, Germany – t.auth@fz-juelich.de

Abstract

Recent advances in nanotechnology have made a whole zoo of particles of different shapes available for applications, but their interaction with biological cells and their toxicity is often not well understood. Experiments have shown that particle uptake by cells is determined by an intricate interplay between physicochemical particle properties like shape, size, and surface functionalization, but also by membrane properties and particle orientation. Particles with sizes comparable to the thickness of the lipid bilayer enter by penetration, while larger particles get wrapped by the membrane. We calculate the energies required to wrap nanoparticles with sizes above *20nm* by lipid bilayer membranes, and characterize particle uptake analogously to thermodynamic phase transitions.[1, 2]

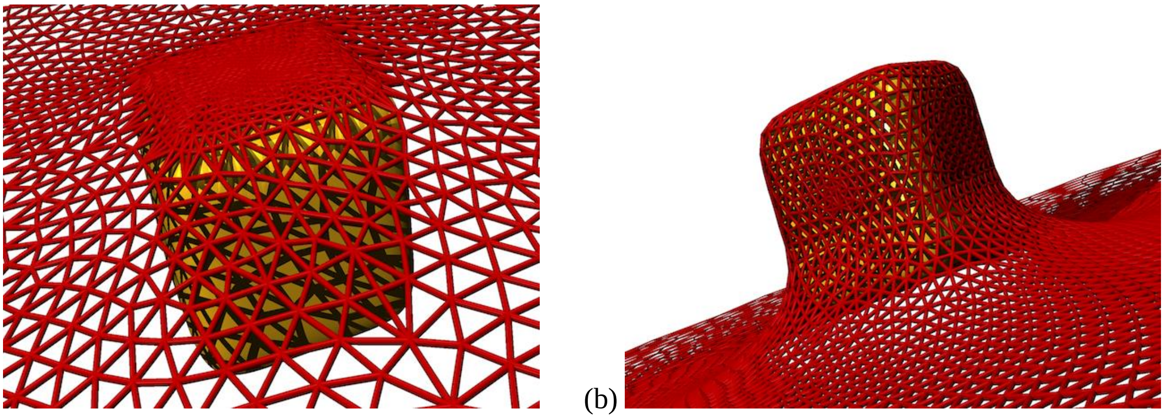
(a) (b)

Figure: Membrane deformation for wrapping of a cube-like nanoparticle. The network of edges and triangles describes the membrane and is used for the numerical calculation of the curvature energy. (a) Nano-cube, shallow-wrapped by a lipid bilayer membrane. (b) Nano-cube, deep-wrapped by a lipid bilayer membrane.

Our work provides a systematic understanding for wrapping of nanoparticles, viruses, and bacterial forms. We present wrapping phase diagrams for various curvature-elastic properties of the membrane, particle-membrane interaction strengths, and particle sizes and shapes. We find parameter regimes with stable unbound, partial-wrapped and complete-wrapped states. The transitions between the different wrapping states can be continuous or discontinuous and may involve reorientation of the nanoparticles. Partially-wrapped states are stable for a large range of membrane properties and particle-membrane interaction strengths for nanoparticles that have edges with high curvatures, such as cube-like and rod-like nanoparticles. In particular for rod-like nanoparticles, we find stable endocytotic states with small and high wrapping fractions; an increased aspect ratio is unfavorable for complete wrapping if the surface area and thus the adhesion energy gain of the particle is fixed.[2] For high aspect ratios and round tips, the particles enter via a submarine mode, i. e., side first with their long edge parallel to the membrane. For small aspect ratios and flat tips, the particles enter via a rocket mode, i. e., tip first with the long edge perpendicular to the membrane.

1. Dasgupta, S.; Auth, T.; Gompper, G. *Soft Matter* **2013,** 9, 5473-5482.
2. Dasgupta, S.; Auth, T.; Gompper, G. *Nano Lett.* **2014,** 14, 687-693.