Bridging scales between solid mechanics and surface chemistry

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It is well established that downsizing mechanical structures make their surface-over-volume ratio much larger than for usual object, so that the possibility to induce mechanical deformations using surface chemistry is significantly augmented. This scaling effect is at the heart of experimental surface science and has been initially exploited for rather fundamental surface science studies focusing on solid electrodes. It has later been used for experimental studies of either the surface relaxation of crystals or the adsorbate-induced surface-stress.

Independantly, the early 80s have seen the emergence of an increasing interest in micromechanical techniques for sensor technologies, the iconic device being a cantilever structure whose deformation is measured using the optical lever technique as for atomic force microscopy (AFM). The rapid development of the latter provided a sensing platform to be tailored in order to make the cantilever bend when the targeted phenomenon occurs. These very deformable structures have thus been quickly used to renew the experimental approach of solid surfaces under various electrochemical processes, or under simple adsorption processes so that the use of such deformable structures to reveal and measure surface stresses is widespread. The possibility to manufacture large and cheap cantilever arrays further triggered the development of micromechanical sensors, so that for both fundamental and applied studies, surface stress is always analyzed or exploited through the mechanical deformation it induces on a mechanical structure. The relation between the surface phenomena and the mechanical deformation it induces is therefore crucial for fundamental surface science studies or innovative applications. One should highlight that this is a multiscale problem by nature, but that these scales are rarely addressed simultaneously.

Second-strain gradient elasticity [1] is used to describe the mechanical effect of surface adsorption on structures. It is illustrated using an elastic solid sphere subject to a cohesion modulus change, which is shown to generally result in a non-uniform strain, thereby illustrating the multiscale nature of the result. The solution obtained for a large number of materials is then analyzed with respect to the sphere's radius, and this toy-model demonstrates that the global deformation results from the interplay between the material's characteristic lengths and the sphere's radius.It is particularly shown that both the material parameters and the sphere's radius can even change the deformation's direction. The elastic energy in the sphere is also shown to be generally misestimated when using Cauchy elasticity and a membrane-based approach to describe surface adsorption. The role of the material itself in the chemo-mechanical transduction goes far beyond the sole Young's modulus of the material, and materials with similar scaling but different higher-grade elastic parameters are shown to display chemo-mechanical transduction efficiencies spanning more than two decades. These findings are thought to be of crucial importance for the experimental investigation of surface effects. This could also probably impact both the engineering of micromechanical biosensors and the control of the chemical activity of surfaces.

References

[1] *Mindlin R.D., Second-gradient theory of strain and surface tension in linear elasticity, Int. J. Sol. Structs., 1, 417-438 (1965).*