Interfacial Forces of 2D Materials at the Oil-Water Interface

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Abstract

Two-dimensional (2D) materials, including graphene and graphene oxide (GO), are a subject of interest for many researchers due to their exceptional properties (strength, conductivity, etc.). These materials, comprised of atomically-thin sheets, may naturally occur stacked together like sheets of paper, but their most interesting properties emerge when separated into individual layers. However, scaling up the processes used to isolate single sheets of some of these materials, particularly graphene, has proven problematic. They can be fiercely resistant to exfoliation, difficult to disperse, and have a worrying propensity to restack. All these problems contribute to the great difficulty these fascinating materials have encountered leaving the lab and entering commercial use. Existing production methods either produce minute quantities, require huge amounts of energy, or involve chemical treatments that transform their properties, typically for the worse. Here, we investigate a method that instead harnesses these difficulties. We force the material to exfoliate itself at the interface between two immiscible solvents, stabilizing the interface and acting as a surfactant with a two-dimensional morphology. In this work we investigate this method and its results in two ways. First, we describe a method we developed using optical microscopy and free software (ImageJ and Gwyddion) that rapidly and inexpensively provides full, simultaneous characterization of thousands of sheets of these materials, yielding both flake area and thickness. We then use this technique to examine the changes induced in 2D material that was exfoliated at the oil–water interface, improving our understanding of the process at the population/production level. Second, we characterize this interaction using force spectroscopy with graphene-functionalized colloidal probes at the surface of pinned droplets of heptane in water. This provides valuable insight into the not-well-understood mechanisms underlying the exfoliation process at the interfacial level. By combining the results seen across these two length scales, our results significantly enhance the understanding of this novel exfoliation process. Additionally, we examine the interactions between another 2D material, mica, and an oil-coated probe in a salt brine using force spectroscopy at high temperature (100 °C) and high pressure (100 atm). These tests are the first demonstration of force spectroscopy in this parameter space and reveal the significant impact of both temperature and pressure on interfacial forces between oil and mineral in this regime. Taken together, our results impact a wide variety of systems including the large-scale production of nanomaterials, nanocomposites, solar cells, sensors, flexible electronics, oil recovery, and catalysis.