Measuring and Modelling Forces and Deformations in Soft Matter

Derek Y. C. Chan[1]

Particulate Fluids Processing Centre, Department of Mathematics and Statistics, The University of Melbourne, Parkville VIC 3010, Australia
and
Department of Mathematics, University of Singapore, Singapore 117543

Two recent experimental advances and adaptations of direct force measurement techniques have provided rich and detailed information about interaction between forces and deformations in soft matter. These results can be interpreted under a unifying theoretical model that gave excellent agreement with experiments and provided detailed dynamic information about interacting soft matter that is as yet unavailable experimentally.

A novel application of the Atomic Force Microscope [1-3] has provided accurate force-displacement data between deformable emulsion drops of less than 100 μm radius and between deformable drops and solid particles. Such dynamic interactions include familiar colloidal forces due to electrical double layer interactions, hydrodynamic forces due to drainage of the nanometer thick liquid layer between the drops/particle as well as deformations of the drops as a result of interactions. Such forces depend on the displacement as well as the relative velocity of the interacting bodies. The presence of hydrodynamic interactions implies that the interaction involves conservative and dissipative elements.

Real-time high-resolution observations of dynamic deformations of a charged deformable mercury/aqueous electrolyte interface of an protuberant mercury drop from a sealed capillary tube of diameter ~2 mm due to an approaching molecularly smooth mica plate were made with an adaptation of the Surface Force Apparatus [4]. The bias voltage on the mercury can be tuned to give a range of repulsive or attractive electrical double layer interactions between the mica and the mercury. Mercury deformation profiles can be resolved with sub-nanometer resolution as a function of time by analysis of video recordings of Fringes of Equal Chromatic Order (FECO) formed by white light interference with the mica. More complex motion of the mica plate and bias voltage changes can be used to create interesting transient responses of the deformable mercury/electrolyte interface under the combined influence of surface forces, hydrodynamics and shape deformations [5].

A theoretical model [6-7] that included colloidal forces, hydrodynamic interactions and surface deformations in a self-consistent way has been developed to analyse the above experiments. Excellent concordance between experiment and theory [8-11] can be achieved within tolerance of experimental input material parameters such as interfacial tensions, drop radii, surface potentials, viscosities and apparatus settings such as drive speeds and spring constants (Fig 1, 2). The theory also offers insight into the transient behaviour of deformable interfaces and the complementary roles of space and time varying disjoining and hydrodynamic pressures in giving rise to novel deformations of soft matter during the course of dynamic interactions (Fig 3).

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[1] D.Chan@unimelb.edu.au http://www.ms.unimelb.edu.au/~dyc

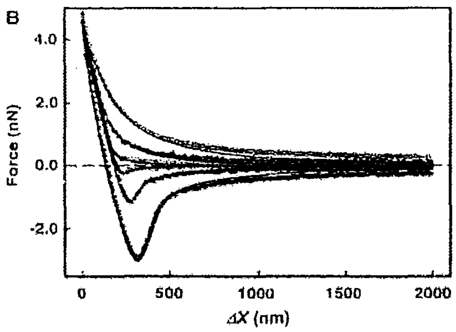

Fig 1a: AFM: Drop-Drop interaction [3]

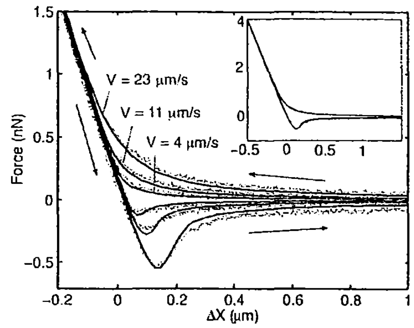

Fig 1b: AFM: Particle-Drop interaction [12]

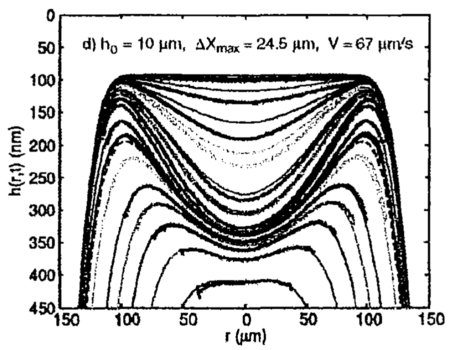

Fig 2a: SFA: Film thinning to equilibrium [8]

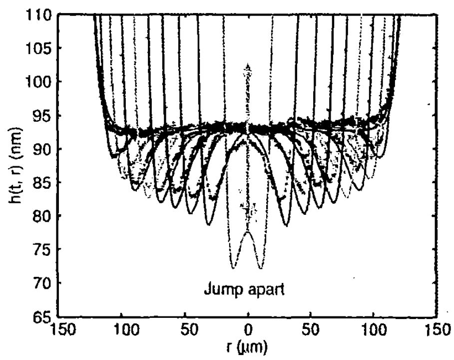

Fig 2b: SFA: Pull-off of a stable film [10]

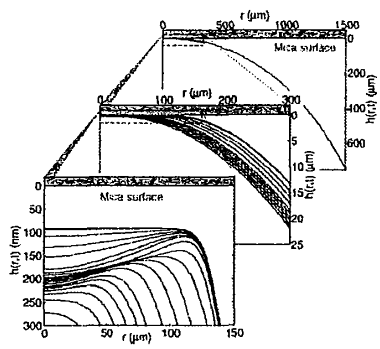

Fig 3a: SFA: Mercury drop profile [8]

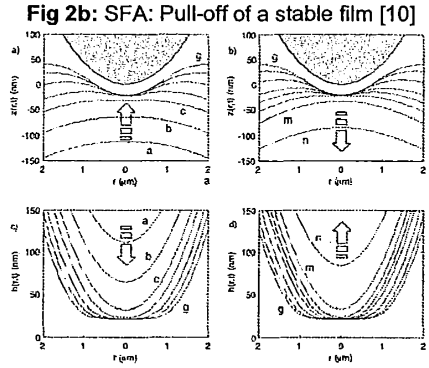

Fig 3b: AFM: Particle-Drop profile [12]

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