A mesoscopic mechanical model of the surface tension

Onofrio Rosario Battaglia and Claudio Fazio

Dipartimento Di Fisica e Chimica, University of Palermo, Palermo, Italy

Abstract. A small insect can float on water. Drops of mercury do not spread on a surface. These capillary phenomena are macroscopic manifestations of molecular interactions and can be explained in terms of surface tension. In this study, we deal with the surface tension from a mechanical point of view. We present a simplified mesoscopic mechanical model of the surface tension and the results of numerical fluid dynamics simulations implemented on the basis of it. We analyse and show the droplet formation without gravity, the droplet formation with gravity when it can drop from a narrow hole like a trickling tap and finally a sessile droplet. Teachers and students can be able to study the surface tension by using our simulation as a "tool" for analysing and discussing the droplet behaviour in several different conditions.

1 Introduction

A small insect can float on water. Drops of mercury do not spread on a surface. These capillary phenomena are macroscopic manifestations of molecular interactions and can be explained in terms of surface tension.

Surface phenomena are important not only to physics but also to neighbouring disciplines such as physical chemistry, life and health sciences and engineering.

The microscopic origin of surface tension lies in the intermolecular interactions and thermal effects, while macroscopically it can be understood as a force acting along the interface or an energy per unit surface area [1] either by using thermodynamics approach [2].

Capillarity is one of the most interesting subjects to teach in condensed matter physics because its detailed understanding involves macroscopic thermodynamics, fluid mechanics, and statistical physics.

There are often obscurities and fallacies in the teaching of surface tension at an elementary level and this is perhaps the reason why the subject is no longer fashionable [1, 3]. For instance, an important question to put to students when the study of the surface tension is tackled from a mechanical point of view is the following: why is surface tension a force parallel to the interface? In fact, it seems obvious that it must be perpendicular to the interface. This question should be very useful in order to understand the physical meaning of the surface tension.

In this study, we deal with the surface tension from a mechanical point of view. A simplified mesoscopic mechanical model of the surface tension and the results of numerical fluid dynamics simulations implemented on the basis of it and of the Smoothed Particle Hydrodynamics method [4] are presented. Smoothed Particle Hydrodynamics method is a method for obtaining approximate numerical solutions to the equations of fluid dynamics by replacing the fluid with a set of particles. In our case we simulate the behaviour of a droplet made of several particles and analyse the dynamics of these particles subject to some boundary conditions.

We study the droplet behaviour in relation to three fundamental phenomena; the droplet formation without gravity by starting from a rectangular geometry, the droplet formation subject to the gravity when it can drop from a narrow hole like a trickling tap and finally a sessile droplet, i.e. the dynamics of a droplet when it is laid on a rigid surface. For each of these configurations the time evolution of the shape of the droplet is shown. Moreover, for a better comparison between our results and the experimental ones a representation of the forces applied to each particle in the droplet is given.

2 Conclusion

A very simplified mechanical model of the surface tension and some simulation results based of the Smoothed Particles Hydrodynamics are presented. Our model takes into account the internal dynamics of the droplet by the overall effect of the forces applied to each particle composing it. Our study emphasises the fundamental role of the repulsive force for obtaining a correct behaviour of the surface of the droplet. Three different experimental conditions relate to three different phenomena involving the surface tension are studied from a numerical point of view. In this way, weakness and strength of our model are verified.

High School and undergraduate students can explore those phenomena by “playing” with our simulation, adjusting some fundamental quantities by using the simulation parameters. Teachers and students can be able to study the surface tension by using our simulation as a “tool” for analysing and discussing the droplet behaviour in several different conditions.

References

[1] Antonin Marchand, H. Weijs and Jacco H. Snoeijer, Bruno Andreotti, Why is surface tension a force parallel to the interface?, American Journal of Physics **79**, 999 (2011); doi: 10.1119/1.3619866

[2] P. Roura,Thermodynamic derivations of the mechanical equilibrium conditions for fluid surfaces: Young’s and Laplace’s equations**,** American Journal of Physics **73**, 1139 (2005); doi: 10.1119/1.2117127

[3] M V Berry, The molecular mechanism of surface tension, Physics Education, **6**(79) 1971

[4] J. J. Monaghan, ``Smoothed particle hydrodynamics,'' Rep. Prog. Phys. **68** 1703–1759, (2005).