Title	Dynamics of Oppositely Charged Emulsion Droplets
Author(s)	Liu, Z; Shum, HC
Citation	Frontiers of Soft Matter Physics: from Non-equilibrium Dynamics to Active Matter, Hong Kong, China, 20-22 January 2014
Issued Date	2014
URL	http://hdl.handle.net/10722/201247
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Dynamics of Oppositely Charged Emulsion Droplets

(Talk #29)

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Two droplets are typically expected to coalesce upon contact due to the minimization of surface energy. However, when droplets are placed under an electric field, the presence of electric stress can lead to even more intriguing dynamics. For example, in a significantly strong electric field, the droplets bounce away from each other upon contact instead of coalescing. In this work, we investigate the dynamics of two oppositely charged droplets. We characterize the dynamics of emulsion droplets by a state diagram using an electrocapillary number and relative separation number. A phenomenon of periodic contact and separation of two oppositely charged droplets, which we term periodic contact, is demonstrated and studied. Two qualitatively different types of periodic contact are identified: “fuse-and-split” and periodic non-coalescence. In regime of “fuse-and-split”, the droplets first coalesce into a jet that remains stable for tens of milliseconds; afterwards, it breaks up into droplets again. In regime of “periodic non-coalescence”, the droplets contact periodically without coalescence. We show this periodic contact occurs because of the interaction between electric stress and surface tension and only exists when the electric conductivity of droplets is relatively high. When droplets are not in contact, the electric stress deforms the droplets against the surface tension and leads to their approach. Upon contact, the electric stress is relieved and surface tension starts to dominate during the evolution of droplets’ interface. By analyzing the surface energy evolution, we show that “fuse-and-split” which enables fluid exchange between the droplets represents a way for droplets to reach a state of minimized surface energy. The periodic non-coalescence which prevents the fluid exchange represents an energy barrier to stop the droplets from approaching the minimized surface energy state. Also, droplets in the regime of “fuse-and-split” will eventually remain separated or transition to the periodic non-coalescence with the change of the droplet shape. Our work enriches the understanding of dynamics associated with charged emulsion droplets as well as other research problems which involve the interplay of electric stress and surface tension.

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