Droplet impacts on cold surfaces

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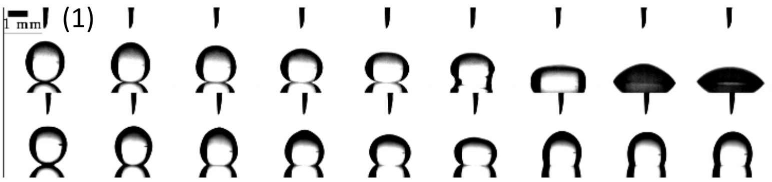
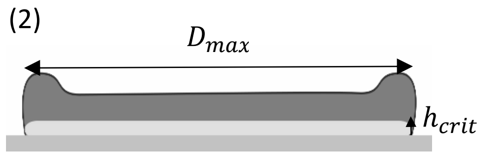
Understanding how liquid droplets impact and spread onto a surface is crucial for several processes ranging from spray coating to printing. Here we focus on drops falling onto a surface that is kept at a temperature below the freezing temperature of the liquid. Such liquid droplets impinging onto cold surfaces are not only of fundamental interest but also important for many engineering processes under extreme conditions. Pertinent examples of the latter are a rain of droplets impacting an airplane wing or a cold car windshield, droplet freezing onto wind turbine wings, droplets of molten solder for electronic component printing and welding and last but not least, 3D printing using molten polymer droplets.

Even if the phenomenon is common, it is very complex: It encompasses different physical phenomena such as spreading dynamics and moving contact lines, the wettability of the surface, thermal transfer between the spreading droplet and the surface and freezing processes with the nucleation of the solid phase.

To investigate this question, we study the impact of water drops (diameter $D_0 \approx$ 2mm) impacting glass surface with a temperature T_s below the liquid freezing point (See Fig.1). We systematically vary the impact velocity V_0 of the droplets, which accelerates the spreading dynamics, to examine the interplay between the spreading dynamics and the freezing dynamics in detail. We find that the final wetted diameter D_{max} is smaller for (very) cold surfaces but that this radius depends crucially on the impact velocity which plays an antagonistic role with respect to the surface temperature (See Fig.3).

Based on these observations and measurements, we propose a simple method to predict the maximum diameter of the liquid drops impacting a cold surface for different temperatures and for different impact velocities: We found that the maximum spreading diameter D_{max} of the droplets after impact can be expressed through simple arguments invoking an ice layer growing from the solid liquid interface and arresting the contact line when the ice layer reaches a critical thickness h_{crit} (See Fig.2). From a knowledge of the ice front velocity, the value of h_{crit}, and the droplet spreading dynamics, the maximum spreading diameter can be obtained for any impact velocity and temperature.





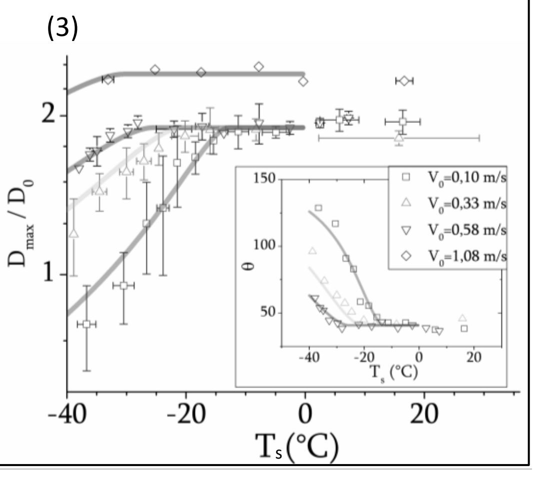


Fig.1: Timelapse of isothermal water drop impact on glass surface (top) and on cold glass surface (bottom) maintained at -40°C.

Fig.2: Representation of the model describing the arresting time: Droplet spreading stops when an ice layer of thickness h_{crit} is formed at the interface.

Fig.3: Experimental measurements of maximum diameter of water drops impact on glass surface for different surface temperature and different impact velocities. Inset shows the final contact angle. Lines corresponds to the model described in Fig.2