Moving contact lines enhance ice nucleation rates

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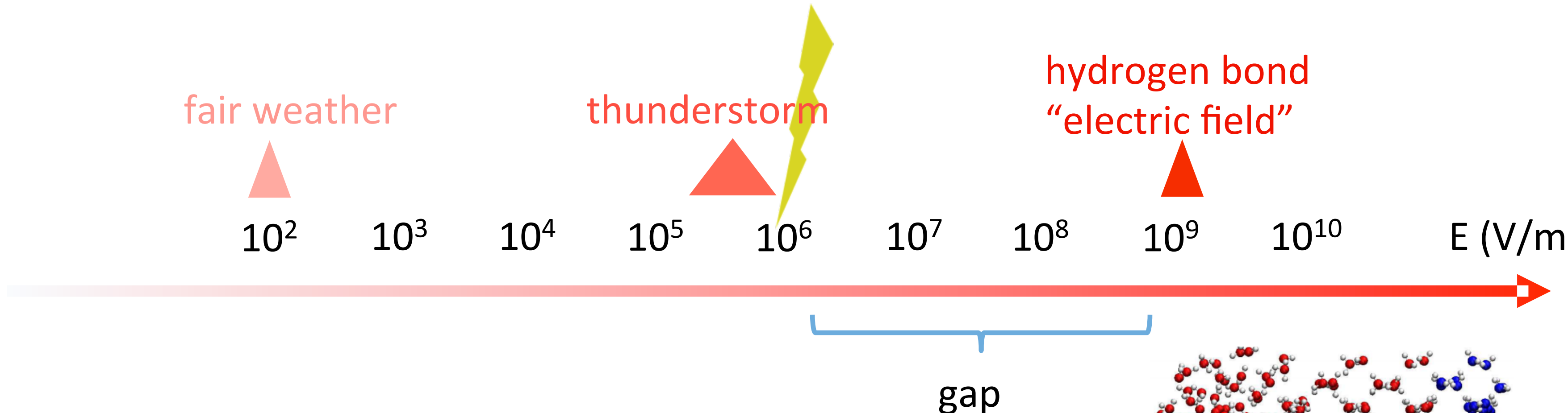
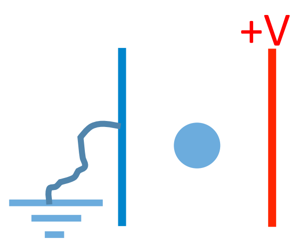
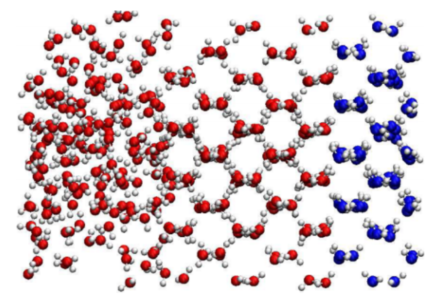
Previous study





Yes/No



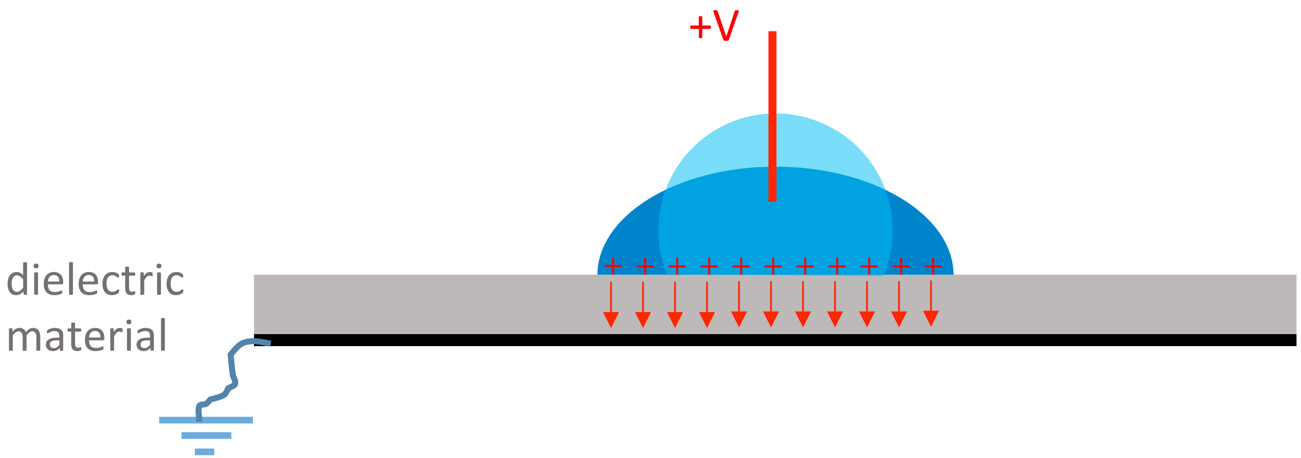
Yan and Patey, JPCA, 2012

Molecular Dynamic Simulation
Yes
if E ~ 10^9 V/m

How to generate **E** larger than **dielectric strength** of air?

Electrowetting

Electrowetting



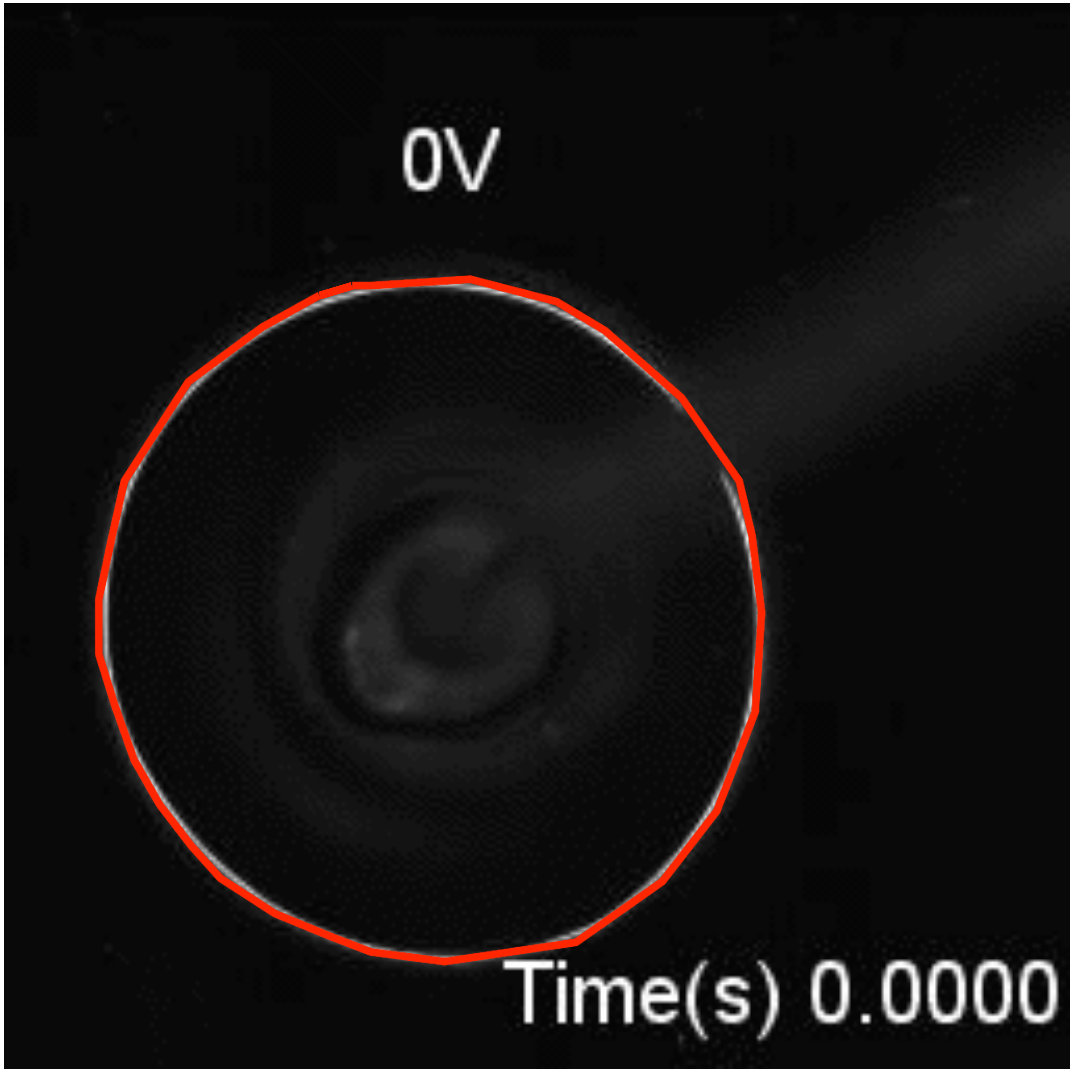
Young-Lippmann equation

$$\cos\theta(U) = \cos\theta(0) + \frac{\varepsilon_0 \varepsilon_d}{2 d \sigma_{lv}} U^2$$

Strong electric field builds between the dielectric layer, like a capacitor. This electric field is usually called the "electrowetting field".

Electrowetting

top view



Boundary movement

Contact angle decreases

Experimental Setup

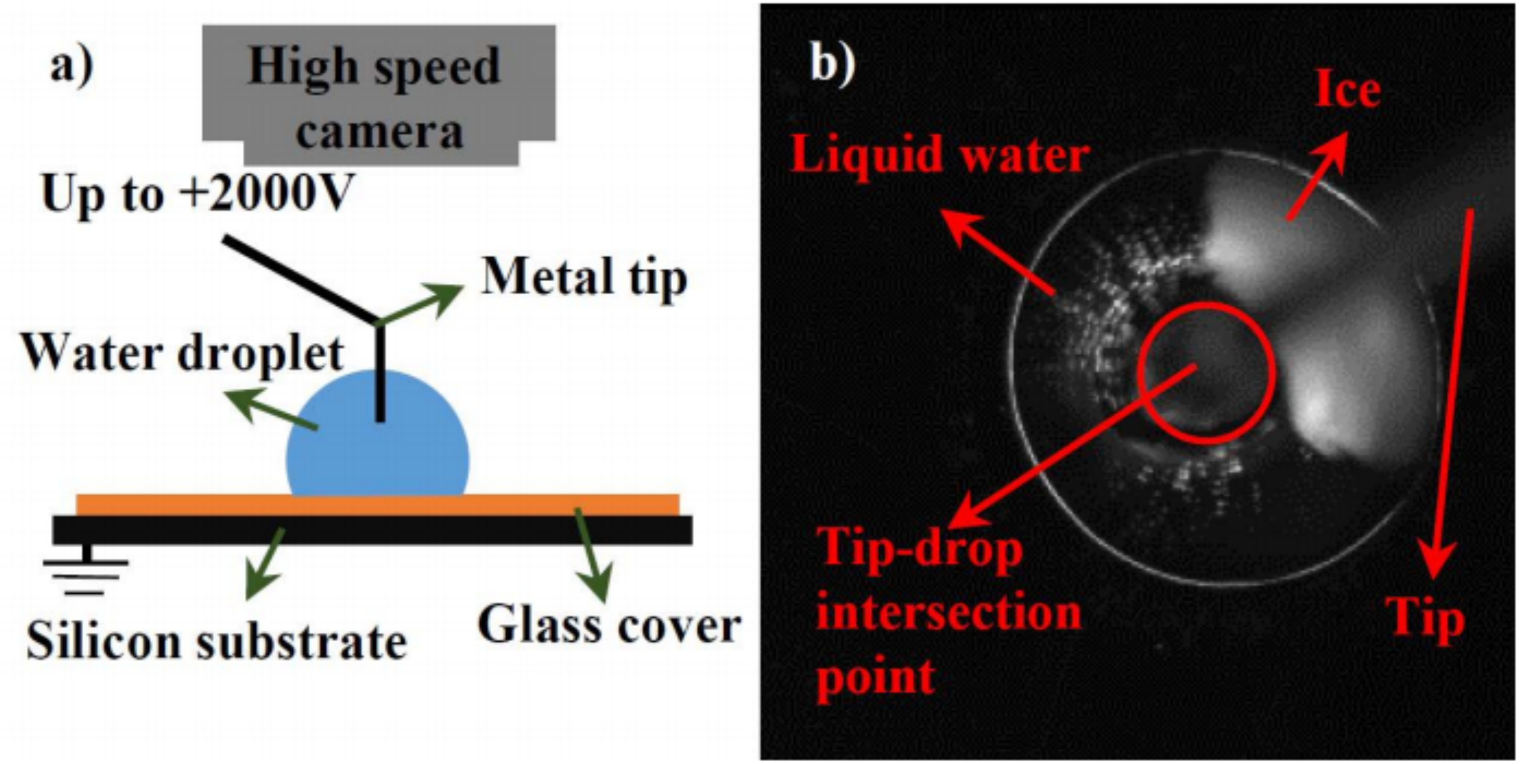
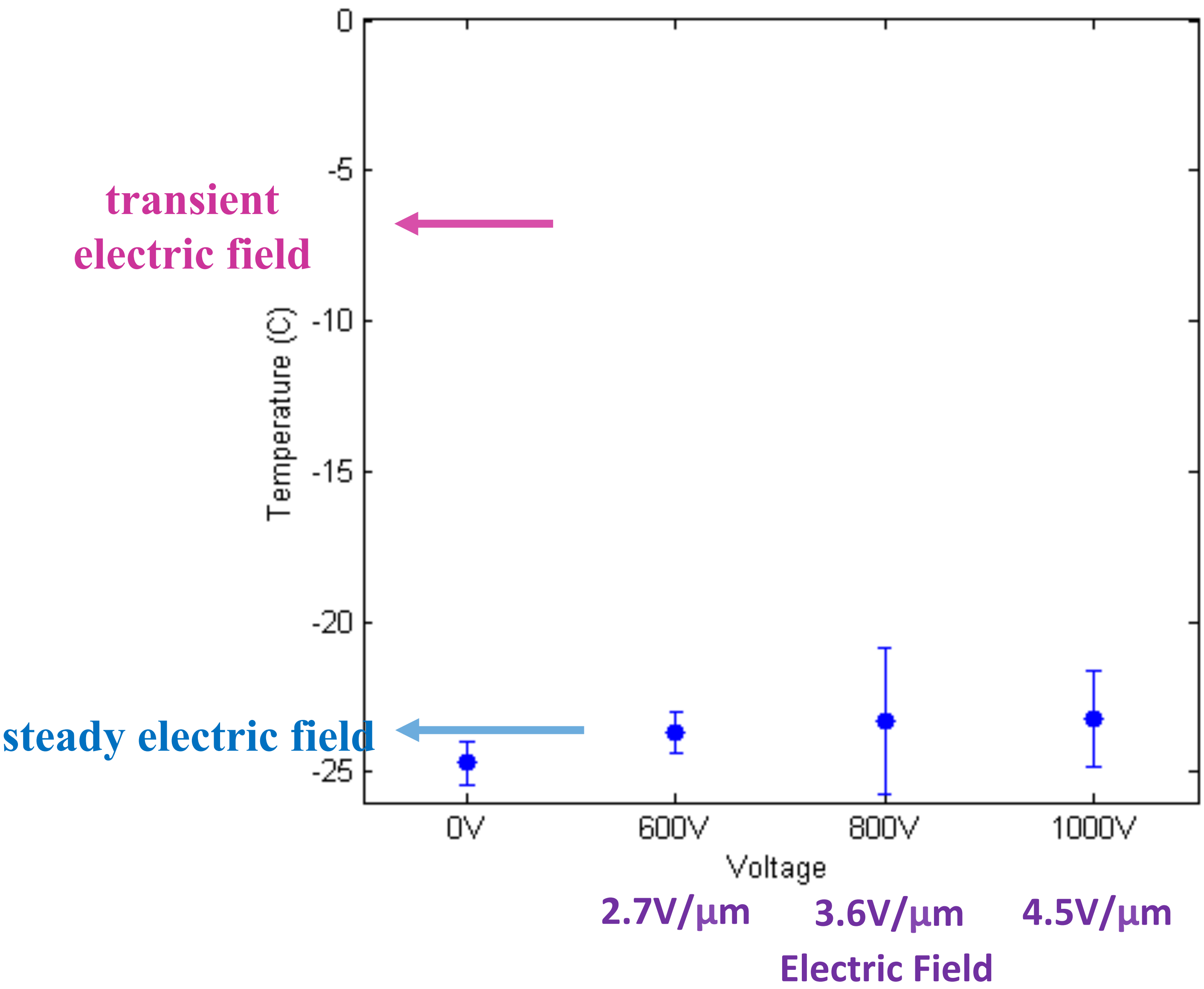


FIG. 1. a) Sketch of the experimental setup from the side, illustrating the electrowetting geometry. b) Top view of a crystalizing droplet from the high speed camera.

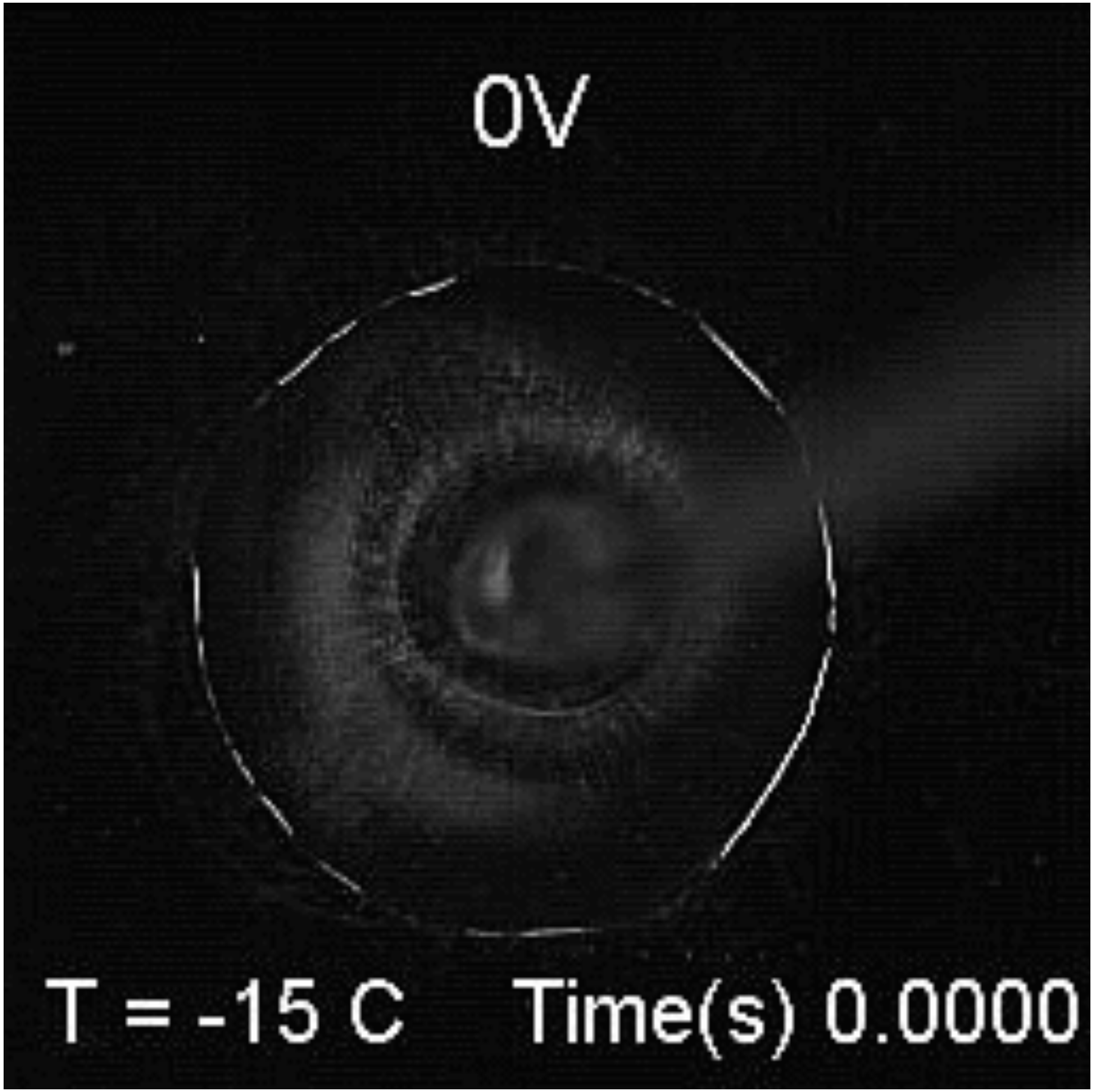
Steady electric field:
Apply a voltage above 0 C and decrease temperature slowly, record freezing temperature.
Transient electric field:
Keep droplet at a temperature, turn **on**/**off** electric field, record whether droplet freezes.

Results



transient
electric field
steady electric field
0
-5
-10
-15
-20
-25
Temperature (C)
0V
600V
800V
1000V
Voltage
2.7V/µm
3.6V/µm
4.5V/µm
Electric Field

Freezing when turning on the field



Moving contact line

Ice nucleation from the edge

Multiple points for ice nucleation

1. Moving contact line alone?

side view

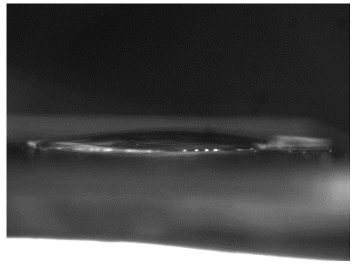
top view

drag back and forth without electric field

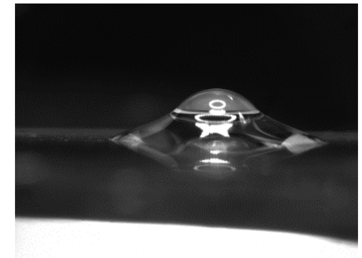
no freezing occurs

2. Transient electric field alone?

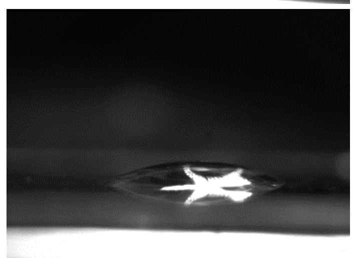
plain glass



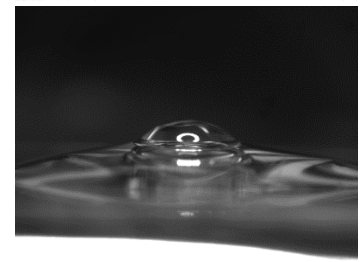
plain glass + oil



mica sheet



mica sheet + oil

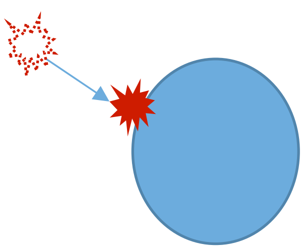


Transient electric field	✔	✔
Boundary movement	x (saturation phenomenon)	✔
Freezing	x	✔

Conclusion

- Steady electric field (E<5V/μm) alone has small effect on ice nucleation.
- Simple mechanical contact line movement alone can't explain our results.
- Transient electric field alone can't explain our results.
- Moving contact lines due to electrowetting enhance ice nucleation rates.

Contact nucleation



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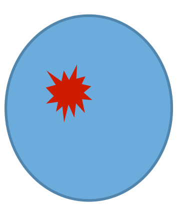
Immersion nucleation



Past and Future

JOURNAL OF GEOPHYSICAL RESEARCH VOL. 68, NO. 15 AUGUST 1, 1963

The Effect of an External Electric Field on the Supercooling of Water Drops

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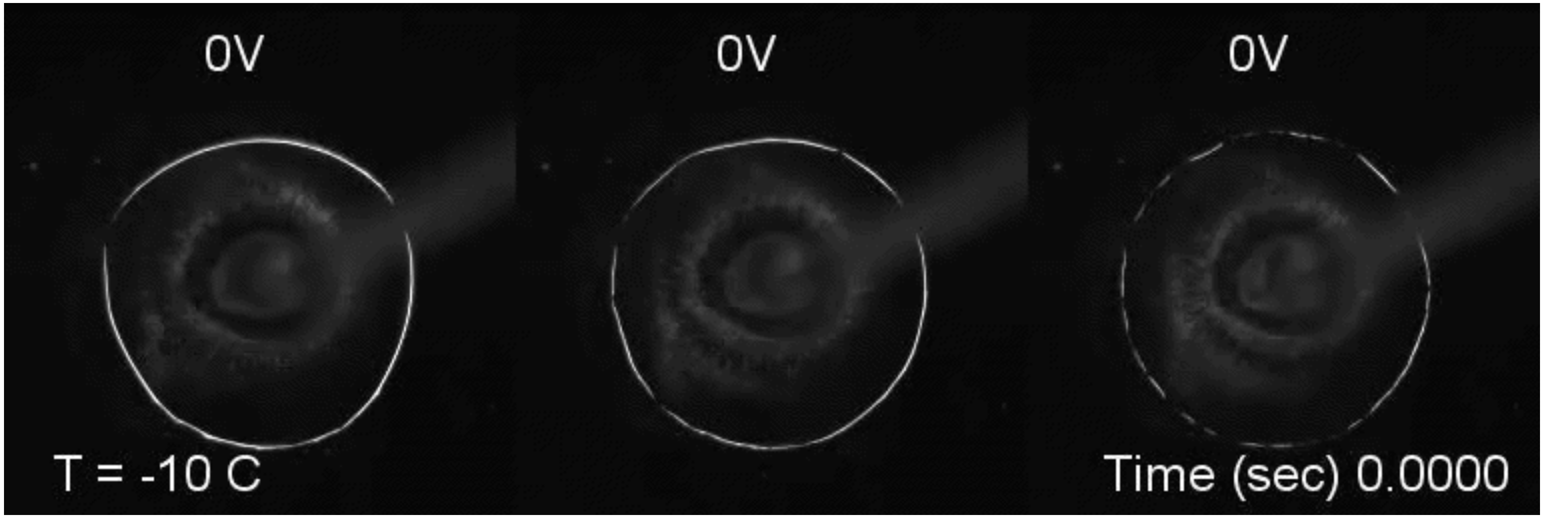
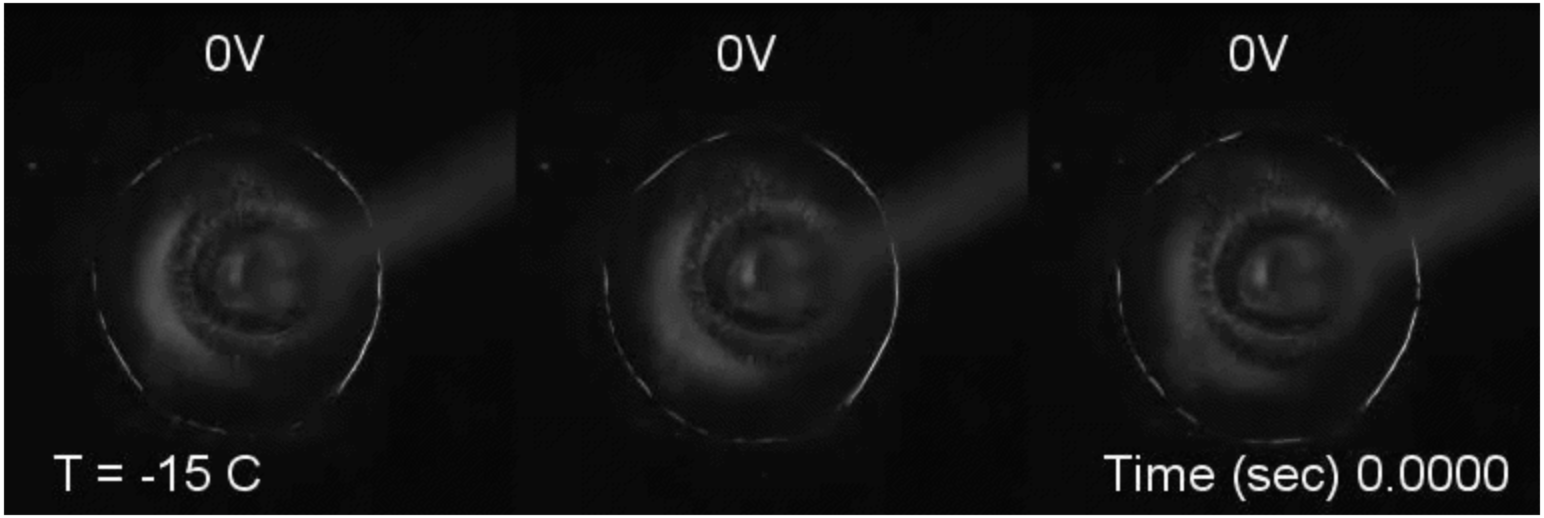
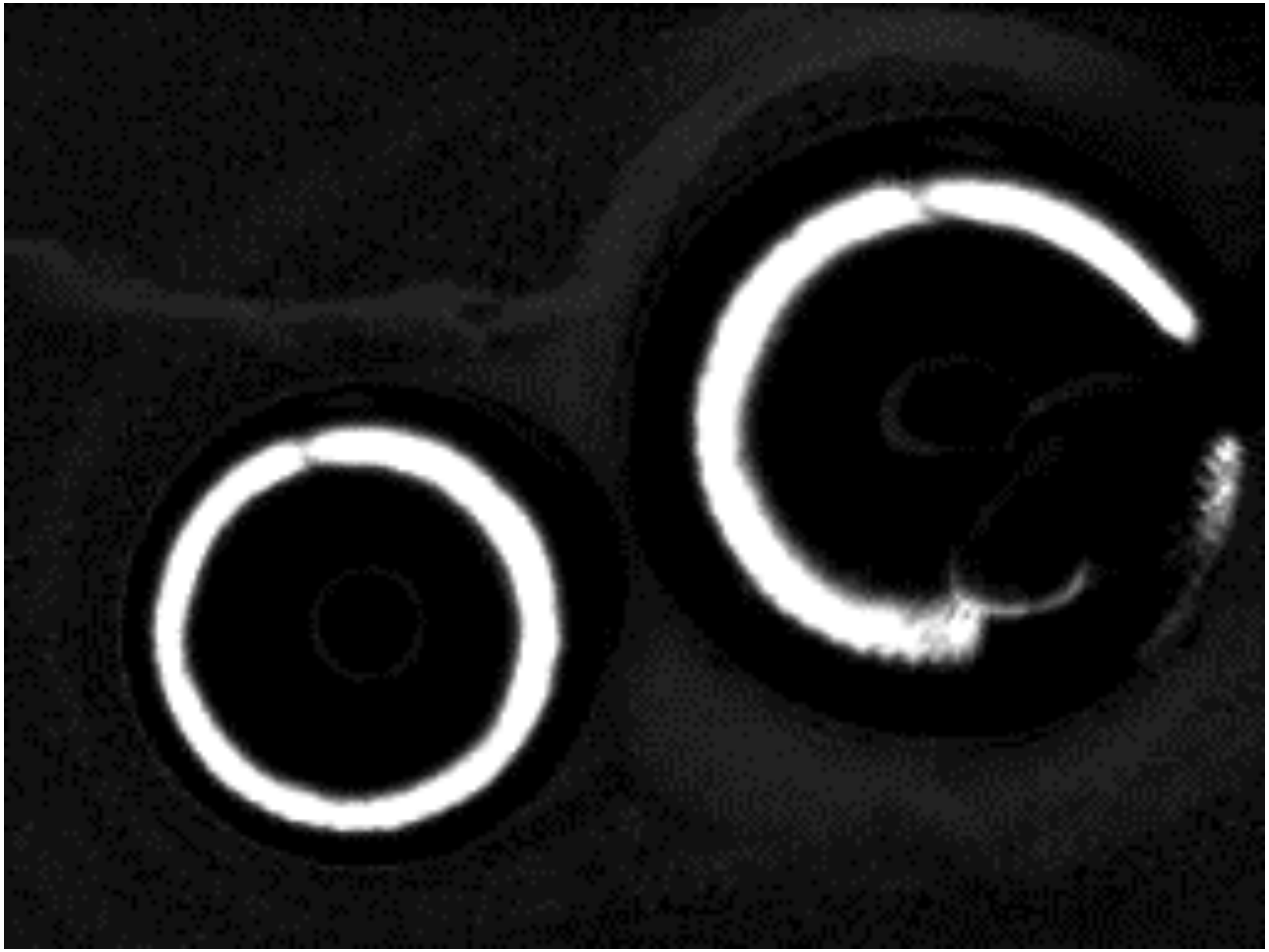
Abstract. The effect of electric fields on the supercooling of water drops was studied by a special experimental technique which permitted the observation of the action on water drops of a dc electric field of 1 to 30 kv/cm. These experiments, documented by a motion picture film, showed that freezing could be initiated in the water drops at a temperature which was only a few degrees below 0°C by applying external electric fields which had field strengths of several kilovolts per centimeter. It was found that the electrofreezing effect was not due to an orientation of water molecules in the water sample, nor was it due to particulate matter produced by sparks or corona discharges since no such discharges took place during the experiments. It was found that the effect was a consequence of the movement of the drop in the electric field along a solid surface. It was concluded from the experiments (1) that an external electric field is able to activate the ice-nucleability of a solid surface and (2) that the characteristics of the effect make it very unlikely that freezing can be initiated by electric fields in atmospheric clouds since the solid surfaces with which the drops have to be in contact during their deformation are not present in mature thunderstorm clouds.

Freezing at -10 C and -15 C







Reference: Yang, Fan, Raymond A. Shaw, Colin W. Gurganus, Su Kong Chong, and Yoke Khin Yap. "Ice nucleation at the contact line triggered by transient electrowetting fields." Applied Physics Letters 107, no. 26 (2015): 264101.