Mechanisms of Heterogeneous Nucleation on Wettable Particles: the Electric Polarization, Osmotic Pressure, Disjoining Pressure, and Micellization Effects
The electric effects and sign preference in ion-induced nucleation
The atmospheric electricity and small nanosized droplets
Nucleation on soluble particles and the osmotic pressure
Nucleation on wettable insoluble condensation nuclei and the disjoining pressure
The general mechanism of heterogeneous nucleation
Joint effects of the osmotic and disjoining pressures: deliquescence and efflorescence
Joint effects of the electric field and the disjoining pressure: charge and sign preference in nucleation on nanosized charged particles
The electric effects and sign preference in ion-induced nucleation

Experiment shows that nucleation in water vapor begins on negative ions at smaller supersaturation ratios than on positive ions, since C.T.R. Wilson (1899).

A strong electric field of the central ion brings nonlinear surface polarization of a nucleating nanodroplet. As a result, the saturation vapor pressure depends on ion charge value and its sign as $\sim q^3$. It also depends on the value and sign of the spontaneous potential jump at the vapor-liquid interface.


The effect of sign preference in nucleation of water on ions

Theory of non-steady state kinetics of ion-induced nucleation kinetics under conditions in the Wilson chamber is formulated with account of the sign preference effect


Experimental data on the number $N^{\pm}$ of nucleating droplets on positive and negative ions as a function of critical vapor supersaturation ratio $\zeta$ were compared with the theoretical predictions.

The atmospheric electricity and small nanosized droplets

In order to explain the atmospheric electricity, about 20 theoretical approaches had been proposed, but they did not stay on thermodynamic ground.

Due to the electric structure of water molecule (its dipole and quadrupole moments), the electric potential jumps at the interface (even in the absence of an external electric field).

Separation of charges in the atmosphere

Anomalous polarization of clouds

Negative charge of rain

Negative charge of the Earth
Nucleation on soluble particles and the osmotic pressure

Soluble particles may consist of salt or soluble organics. Surface active organic compounds can be accumulate at solution at the droplet surface and form an adsorption monolayer. If the volume concentration of the surfactant exceeds the critical micelle concentration, the substance can be in the solution within the droplet in the form of small stable aggregates – micelles. Even though the classical Köhler theory takes into account the osmotic pressure effects, it does not consider adsorption and micellization effects.
The theory can now predict the threshold vapor supersaturation as a function of the initial particle size ($n_n$ is the number of molecules in the soluble particle). For very small particles, the threshold vapor supersaturation can be considerably below than that predicted by the Köhler theory. Thus, if the surfactant has a high solubility in the condensate, the adsorption can stimulate heterogeneous nucleation.

Nucleation on small insoluble particles is usually considered in the frameworks of the Volmer-Fletcher theory. It was assumed in the Krastanov theory that activity of such particles can be explained by the fact that droplet growth starts from the size of the particle and requires smaller activation energy. Such approach could not explain the existence of ultra-small critical vapor supersaturations for this type of nucleation.

The general mechanism of heterogeneous nucleation

The typical behavior of the work $W$ of droplet formation as a function of the number $v$ of condensate molecules in the droplet for homogeneous and heterogeneous nucleation. Curves 1, 2, 3 and 4 illustrate the influence of vapor supersaturation $\zeta$: 1 – undersaturated vapor, 2 – barrier nucleation in supersaturated vapor, 3 and 4 – barrierless nucleation in supersaturated vapor.

The initial stage of nucleation on soluble solid particles in the atmosphere of a solvent vapor with formation of droplets consisting of the liquid solution film around incompletely dissolved particles (the deliquescence stage) attracts now a considerable attention due to abilities of obtaining a stable droplet distribution at aggregative equilibrium in undersaturated vapor. The reversal process (the efflorescence stage) gives a possibility to modify the size and initial composition of aerosol particles.

Core-shell aggregate in an ambient vapour: phase $\gamma$=soluble core; phase $\alpha$=enveloping liquid film (solvent shell); phase $\beta$=solvent vapour.
The deliquescence stage illustrates the significance of the disjoining pressure in film nucleation.

\[ b = \ln S \]
Two dimensional theory of deliquescence


Joint effects of the electric field and the disjoining pressure: charge and sign preference in nucleation on nanosized charged particles

- Do the properties of bulk liquid phase be achieved within a film around the solid particle?
- What is the role of hydrophobicity or hydrophilicity of the particle surface?
- How the joint description of the effects of electric field and the disjoining pressure can be incorporated?

The initial stage of the formation of a droplet around the charged solid particle.