Formation of Nanoparticles in Gaseous Reactive Systems

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The synthesis of nanoparticles is an essential part of nanotechnology which is concerned with the development and utilization of structures and devices scaling between individual molecules and features below 100nm. Thin films, lateral structures, and very small particles are examples of nanotechnology. Nanoparticles are structures having a reduced size in all three dimensions which is called reduction from 3d toward 0d. Because of the large surface-to-volume ratio, quantum and boundary surface effects are becoming dominant. Therefore, nanoparticles have interesting properties compared to bulk materials including thermodynamic, magnetic, optical, electronic, chemical, and mechanical behaviour, which are only a result of their limited size.

For the synthesis of nanoparticles various techniques are known which can be classified into colloidal (liquid phase) or aerosol (gas phase) systems. To the later ones belongs reactive aerosol synthesis which is very similar to combustion. It can - depending on the precursor material - proceed through a self-sustaining or pyrolysis type of reaction. Reactive gasphase synthesis of nanoparticles offers some advantages over material synthesis by other, e.g. wet chemical processes, mainly because of better product control such as particle size, crystallinity, degree of agglomeration, and chemical homogenity. The conversion of gaseous precursors to solid/liquid particles in a reactive gas flow is an exciting research area. The fundamental are not fully understood, especially the homogeneous gas phase kinetics, the particle growth and coalescence kinetics, and the early nanoparticle synthesis. The various mechanisms that can be found in gas-to-particle conversion include five basic steps which can proceed purely sequential or more or less interconnected are:

(1) gas phase kinetics of precursors forming condensable species,
(2) nucleation of supersaturated vapour forming clusters and early particles,
(3) surface growth of primary particles by heterogeneous chemical reactions or by physical vapour condensation,
(4) particle agglomeration by Brownian motion,
(5) particle coalescence driven by the reduction in surface free energy.

In the plenary lecture various examples for the different reactive gas-to-particle conversion steps will be demonstrated including shock tube kinetics of precursor reactions, flame synthesis of oxidic nanoparticles, heterogeneous gas/particle reactions, and formation of coated nanoparticles. A detailed understanding of underlying physico-chemical processes needs application of modern in-situ and ex-situ diagnostics for gas phase species and particles.