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A standardized nucleation nomenclature

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Study of cloud particle nucleation requires considerable referral to phase transitions among the solid, liquid, and gaseous states of water substance. Presently one may select terminology from the antonym pairs melting-freezing referring to the solid-liquid transitions, evaporation-condensation referring to the vapor-liquid transitions, and sublimation-deposition referring to the solid-vapor transitions. Each of the six antonyms, while suggesting something of process mechanism, serves primarily to indicate direction of the process involved. This terminology provides approximate definition for homogeneous or heterogeneous cloud particle nucleation and growth. It was in referral to particle growth that McDonald (1958) introduced the sublimation antonym, "deposition," which has served to significantly clarify recent literature. The desired precision in nucleation terminology, however, has not been attained. Considerable ambiguities remain in denoting the phase transitions pertaining to nucleation, particularly when the solid state is involved. The existence of multiple meanings of the various phase-change terms contributes to the confusion, as does the application of this terminology to nucleating mechanisms which we do not as yet fully understand.

A cloud physicist speaks, for example, of "deposition nuclei" as those particles upon which an ice crystal may grow by "deposition"; he speaks of "deposition" in reference to the transition of water substance from the vapor phase to the solid phase, without passing through an intermediate liquid phase.[1] Ambiguity arises from the fact that the cloud physicist also speaks, for example, of ". . . the deposition of the first few molecular layers . . ." (Houghton, 1951), and the phyiscist and chemist speak of "vacuum deposition" of thin films. A "deposit" of a few molecules or a thin film "deposition" does not establish a bulk phase; it is impossible to specify whether such "deposits" are solid or liquid. Indeed, in reference to what we now call "deposition nuclei," Houghton (1951) ". . . conceded that the deposition of the first few molecular layers on such a nucleus need not be in the form of ice." Thus while McDonald (1958) used the above phrases in defense of the term "deposition" for specifying the vapor-to-solid transition, it becomes obvious from these quotes that "deposition" may apply equally well to the vapor-to-*film* transition. Furthermore, such a film "deposit" may lead to establishment of either the solid *or the liquid* phase.

Other sources of confusion exist. The *Glossary of Meteorology* (Huschke, 1959) defines a "freezing nucleus" as "any particle which, when present *within* a mass of supercooled water, will initiate growth of an ice crystal about itself."[2] This definition is incomplete. It appears to be accurate when the particle is an *internal* embryo of homogeneous nucleation. It could also describe heterogeneous nucleation when the foreign nucleating particle is contained *within* the supercooled water. However, there remain the possibilities that homogeneous nucleation of a liquid-to-solid transition can be initiated by an embryo at the surface of the water mass, and that heterogeneous nucleation may occur from a foreign particle present *on the surface* of the supercooled water. One may devise several definitions of a "freezing nucleus."

Yet another ambiguity in the literature is the frequent mention of nucleation as involving a "phase transition to the more condensed state" with reference to *either* the liquid or the solid; this confuses the term "condensation." The need is evident for a more precise nucleation nomenclature.

A group of seven scientists including cloud physicists, atmospheric chemists, and a nucleation engineer,[3] discussed the nomenclature problem in depth. From this group a committee composed of the authors was selected to make the following recommendations: A nomenclature should be introduced for the purpose of clarifying terminology problems of nucleation and associated nuclei. The recommended nomenclature should be precise and as basic as possible. It should be interdisciplinary: cloud physicists, chemists, physicists, engineers, etc., should find it equally applicable.

An already common nomenclature is that used to symbolize the latent heats of the various phase transitions. Thus L_{vl}, L_{ls}, and L_{vs} symbolize the latent heats of the vapor-to-liquid, liquid-to-solid and vapor-to-solid transitions, respectively, while the latent heats of the inverse transitions are denoted by L_{lv}, L_{sl}, and L_{sv}, respectively. A direct extension may be made to devise a standard nucleation nomenclature. The latent heat subscripts refer to *bulk* states. This practice shall be conserved. Thus V, L, and S shall be used to denote the vapor, liquid, and solid phases, respectively, as they appear in bulk at some stage of nucleation. A bulk phase exists when there is present a volume of substance within the phase, in which the properties of the substance are independent of position. (The consequence of gravity in establishing pressure gradients is neglected in this definition.)[4] To designate direction of the phase change(s) the letter designations shall be written in order of phase appearance, as is done with the latent heats.

[1] These definitions follow directly from those in the *Glossary of Meteorology* (Huschke, 1959) for "sublimation nucleus" and "sublimation," but with the term "sublimation" replaced by the more recent term "deposition."

[2] Authors' italics.

[3] A scientist involved in the engineering aspects of nucleation and nuclei production.

[4] A more rigorous definition of "bulk phase" may be found in many existing texts, e.g., Guggenheim, E. A., *Thermodynamics,* North Holland Publishing Company, 1949.

Using such nomenclature, the vapor-to-solid phase transition shall be simply termed the "VS transition" and the nucleus which initiates the complete transition shall be a "VS nucleus." In like manner the terms "VL transition" and "VL nucleus" apply to vapor-to-liquid nucleation, and "LS transition" and "LS nucleus" apply to liquid-to-solid nucleation. Inverse transitions may be designated as the "SV," "LV," and "SL" transitions, respectively. One may speak of the latent heat of the VS transition, that of the SV transition, etc.

Certain nucleation processes may involve the appearance of each of the V, L, and S phases. In such cases, reference can be made, for example, to the "VLS transition" and the "VLS nucleus." Combinations are possible for whatever transition is observed.

The clarification of nucleation nomenclature achieved by use of the "V, L, S" terminology becomes quite evident when the above-mentioned ambiguities are considered. Precision is improved. The "V, L, S" terminology is basic and should be equally applicable to any scientific discipline. It is urged that this terminology be adopted in future discussions of nucleation. Comments and discussions are invited.

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