CORRESPONDENCE

"Deposition"—a proposed antonym for "sublimation"

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In discussions of cloud-particle growth, it is often necessary to consider, at one point or another, changes of phase to and from the solid, the liquid, and the gaseous states of water. Present terminology contains the antonymous pairs melting-freezing referring to solid-liquid transitions, and evaporation-condensation referring (at least primarily and typically) to liquid-vapor transitions, but does *not* include an antonymous pair referring specifically to solid-vapor transitions. This latter fact leads to confusion in certain cloud physics discussions, confusion that is probably more or less familiar to all meteorologists. For *both* the solid-to-vapor and the inverse vapor-to-solid transitions, the single term, "sublimation," must serve at present. The result is that one can never be both concise and precise in discussing processes such as the Bergeron ice-crystal process and related phenomena wherein it is not infrequently necessary to refer, at one stage or another, to all six possible types of phase change. My own observation is that usage in the cloud physics literature is about equally divided between use of "evaporation" or "sublimation" for the one, and "condensation" or "sublimation" for the other (inverse) phase change. This situation has long needed rectification, and the recently increased interest in the details of cloud microphysical processes makes it still more desirable to clarify terminology and to introduce one new term in order to achieve precision of expression without circumlocution.

Since all of the phase-change terms referred to above have been taken over from the literature of physics and chemistry, it may seem rather surprising that workers in those latter fields have not already found it necessary to introduce a sixth term; but one can see that their failure to make such an introduction is related to the comparatively low degree of complexity of the laboratory systems under discussion in those fields as contrasted with the multi-phase complexity typical of an active cloud. Curious as to overall practices, I systematically examined usages in the textbook literature of heat, thermodynamics, and physical chemistry, and have concluded that use of the term, "sublimation," outside of the field of meteorology, is now almost uniformly restricted to the solid-to-vapor transition. That is, the chemist and the physicist simply do not have any distinct and formalized term denoting only a vapor-to-solid phase transition; instead, they usually rely on "condensation" to fill their needs fairly unambiguously. Needless to say, that latter solution would be extremely ambiguous if adopted by cloud physics workers—even *more* ambiguous than the present meteorological practice of using "sublimation" for two distinctly inverse processes. As a typical example of the generally accepted chemical definition, one standard chemical dictionary[1] defines "sublimation" as "the transformation of a solid directly to the gaseous condition without passing through the liquid state," while a recently published physics glossary[2] similarly defines the verb "sublime" as "to pass from the solid directly to the gaseous state without melting." Somewhat to my surprise, I found that this current physico-chemical usage is *not* in accord with the definitions preferred in authoritative general dictionaries, where the primary definition embraces condensation of the vapor back to the solid state. Thus Webster's International[3] gives the definition, "To pass from the solid to the gaseous state, and again condense to solid form, without apparently liquefying," and essentially this definition is also given by other such authorities.[4,5] Nevertheless, this usage is relatively rare in the technical literature, and in the several dozen sources I examined, I found *no* physics reference using this extended definition, and only a few chemistry references using it. Thus, one has the peculiar circumstance that the meteorologist has adopted a term from physics and chemistry and has given it a denotation which, though identical with that still preferred by lexicographers, is rather confusingly different from the meaning now employed by almost all physicists and chemists.

Hoping that etymology might help either in understanding the original meaning of the term or in coining some appropriate new antonym for meteorological use, I consulted several appropriate references[4,5,6] and concluded that the *ultimate* origin of "sublimation" is uncertain, but that the meaning still cited by

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[1] Honig, J. M., *et al*, *The Van Nostrand Chemist's Dictionary*. D. Van Nostrand Co., New York, 761 pp., 1953.

[2] Michels, W. C., *et al*, *The International Dictionary of Physics and Electronics*. D. Van Nostrand Co., New York, 1004 pp., 1956.

[3] Neilson, W. A., *et al*, *Webster's New International Dictionary*, 2d ed., unabr. G. and C. Merriam Co., Springfield, Mass., 3194 pp., 1954.

[4] Onions, C. T., *ed.*, *The Shorter Oxford English Dictionary*, rev. ed. Oxford Press, London, 2475 pp., 1933.

[5] Whitney, W. D., *ed.*, *The Century Dictionary and Cyclopedia*. The Century Co., New York, 7046 pp., 1911.

[6] Skeat, W. W., *An Etymological Dictionary of the English Language*. Oxford Press, London, 780 pp., 1946.

lexicographers as the preferred meaning (and currently used by the meteorologist) has its *immediate* origin in the once important terminology of alchemy. The immediate root was the Latin *sublimis*, meaning "high, lofty, ethereal, purified," and these somewhat emotionally tinged adjectives suited well the alchemist's mystical conceptions of the effects of the physical processes accompanying evaporation and subsequent condensation of certain volatile solids. Both literally and figuratively, such distillation was to the alchemist a purifying and hence elevating process, and in order that "sublimation" in this arcane sense should carry its intended connotations, it quite clearly had to denote *both* the original solid-to-vapor *and* the final vapor-to-solid transition. The modern physicist and chemist have, then, evidently thrown away half of the earlier meaning of "sublimation" in conventionally applying it just to the vaporization of solids.[7] My hope that some suitable Latin root for a needed antonym to the chemist's usage might be discerned by examining the original roots was not only thwarted in the above sense, that "sublimation" cannot, in its primitive sense, have an antonym of the type sought, but also in that the earlier Latin etymology of the adjective *sublimis* is apparently too uncertain to aid in constructing an antonym. Expert conjecture suggests that the word derives from *sub* meaning "under" or "up to," plus *limen*, meaning "threshold" or (!) "lintel," with the sense being that anything which is *sublimis* reaches up to the lintel, a sacred site according to Roman familial belief. It seems difficult to extract anything cloud physically useful from that. It appears to be fairly clear that etymology is best abandoned at this point, that current physical and chemical usage should be adopted by the meteorologist in restricting "sublimation" to just the solid-to-vapor transition and that some antonym should be defined without direct regard to the obscure roots of this word.[8]

After trying without very satisfactory results to conceive some wholly new word coined from Latin or Greek roots for the purpose of describing the vapor-to-solid transition, it seemed to me that the process could be clearly enough identified simply as "deposition," at expense of only slight ambiguity with respect to other casual technical uses of that word, so I wish to recommend that this usage be adopted in meteorological terminology. One would speak, then, of the growth of ice crystals by deposition (depositional growth), and one might speak, if necessary, of the associated heat of deposition. The present term, "sublimation nucleus" would be replaced by the more apt "deposition nucleus." In a discussion of the kinetics of homogeneous nucleation one might speak of water molecules subliming from the smaller crystals and undergoing deposition on the larger crystals, etc.

Having concluded some time ago that "deposition" might serve rather satisfactorily in this role, I have been pleased subsequently to come upon a surprising number of passages wherein "deposition" has, in fact, already been used informally and descriptively in exactly the presently recommended sense in papers in the field of cloud physics as well as in chemistry and physics, thus further supporting this term's claims to suitability. I shall quote enough of these instances to demonstrate that the meteorologist need not be reluctant to adopt this usage on the ground that it is inherently awkward or unnatural to use the word as here suggested. For example. Ludlam[9] writes, ". . . down to a certain temperature below 0C, direct deposition of vapor as ice is not to be expected," and Mason and Ludlam[10] write, "If ice crystals are to grow easily on a foreign substrate by direct deposition of water vapor. . . ." Similarly, Houghton[11] writes, ". . . the deposition of the first few molecular layers on such a nucleus may not be in the form of ice . . . ," so we see meteorologists are prepared to use the term even without formal definition. The physicist speaks of "vacuum deposition" of thin films. Buckley,[12] in describing the growth of metal crystals from the vapor phase speaks of, "a temperature of 1000C for the deposition." These and other uses in similar contexts suffice to indicate that the recommended meaning will surely not conflict with current usage in physics. Similarly, in the chemical literature it has been possible to find a number of instances wherein "deposition" was used in essentially the proposed sense. Thus in one standard text,[13] one finds a figure whose caption refers to ". . . equilibrium between molecules evaporating from an iodine crystal and gas molecules depositing on the crystal;" and in another,[14]

[7] It deserves final emphasis that current meteorological usage, whose revision is here being urged, follows *neither* that of all physicists and of some chemists who use "sublimation" only for the solid-to-vapor transition, *nor* the usage of those chemists who still employ this term in its original sense to denote a two-way transition from solid to vapor and back to solid. The meteorologist has, instead, adopted the very confusing practice of using this single term to denote *either* one *or* the other, or *both* of the inverse transitions between solid and vapor, with a strong bias in actual frequency of usage towards the latter (as in "sublimation nucleus"), *i.e.*, with a strong bias towards the exact opposite of standard usage in the field of physics.

[8] It is of passing meteorological interest to note that, on the other hand, etymology *is* illuminating and relevant in the case of the closely related term, "subliminal," encountered, for example, in visibility theory.

[9] Ludlam, F. H., "The forms of ice-clouds." *Quart. J. r. meteor. Soc.*, **74**, 39–56, 1948.

[10] Mason, B. J., and F. H. Ludlam, "The microphysics of clouds," in *Reports on progress in physics*, **14**, A. C. Stickland, ed. The Physical Society, London, 412 pp., 1951.

[11] Houghton, H. G., "On the physics of clouds and precipitation," in *Compendium of Meteorology*, T. F. Malone, ed. Amer. Met. Soc., Boston, 1334 pp., 1951.

[12] Buckley, H. E., *Crystal Growth.* Wiley, New York, 571 pp., 1951.

[13] Pauling, L., *College Chemistry*, 2d ed. W. H. Freeman, San Francisco, 685 pp., 1955.

[14] Richardson, L. B., and A. J. Scarlett, *General College Chemistry*, 4th ed. Henry Holt, New York, 704 pp., 1957.

the author points out that "gas may be changed into the solid again by deposition on a cold surface." In all, I think that one can justifiably conclude that adoption of the herein proposed specific definition of "deposition" will really be chiefly a formalization of now loose practice based on the evident aptness of this term for identifying the vapor-to-solid transition.

I would urge, therefore that the term "deposition" be adopted as denoting only the vapor-to-solid phase change, and that "sublimation" be limited (particularly in purely meteorological contexts) *only* to description of the solid-to-vapor change. Because it seems almost equally desirable from the viewpoint of chemist and physicist that this present defect in terminology be remedied, I am making the present recommendation by correspondence to one journal in each of these other two fields. If the recommended change and addition in terminology can be accomplished, six distinct terms will be available for unambiguously specifying the six distinct physical processes which play important roles in the growth and dissipation of cloud and precipitation particles, and a small but annoying point of confusion will have been eliminated.