



Received: 17-08-2026
Accepted: 27-09-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Calculating the Temperature Where Rain Droplets in a Cloud Become Ice Particles II

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Abstract

On June 4, 2012, Jennings (2012) ^[1] published his theory of how a polystyrene solution superheats and nucleates. From Jennings (2012) ^[1] came Jennings (2024) ^[2] where the formula for raindrop formation in a cloud is presented. Then was published Jennings (2026a) ^[3] where the following equation for the rain dew point was derived.

$$T_o - T = (3 k T_o^2 / \sigma_o a_o) (P^*_{H_2O} / P_{air})$$

For Jennings (2025) ^[4] there is the formula for snow formation in a cloud related to ice formation in a supercooled bath.

$$T = D (7.14 \times 10^7) / (k n_s a \Delta T^{0.69})$$

Now $\Delta T = T_o - T$, where T_o = melting temperature Kelvin of ice and T = temperature Kelvin of the bath or supercooling

limit in the cloud. In a paper, we eliminated $T_o - T$ between these two equations to get this result. Jennings (2026b) ^[5].

$$T = D (7.14 \times 10^7) / (k n_s a ((3 k T_o^2 / \sigma_o a_o) (P^*_{H_2O} / P_{air}))^{0.69})$$

This paper is version II of the rain droplets supercooling to become ice particles paper. Here new expressions for D and $P^*_{H_2O}$ are used. In the text of the paper, the author will present how to calculate T , where the rain droplet has supercooled enough to become an ice particle. Another aspect of this paper is to point out that cloud seeding should be done in the Rocky Mountains that feed the Colorado river. The clouds in the mountains could be seeded with NaCl, AgI, dry ice or even possibly CH₃-O- Na⁺. Jennings (2022) ^[6].

Keywords: Dew Point, Cloud Nucleation, Cloud Seeding, Supercooling, Colorado River

Introduction

We need to put in the values for the variables in the third equation in ABSTRACT, here as (1).

$$T = D (7.14 \times 10^7) / (k n_s a ((3 k T_o^2 / \sigma_o a_o) (P^*_{H_2O} / P_{air}))^{0.69}) \quad (1)$$

To predict D (self-diffusion coefficient of water) we look to Price, *et al* (1999) ^[7]. They give this formula.

$$D = D_o T^{1/2} (T / T_s - 1)^\gamma \quad (2)$$

Where

$D_o = 7.66 \pm 0.24 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$, $\gamma = 1.74 \pm 0.10$ and
 $T_s = 219.2 \pm 2.6 \text{ K}$
 $k = 1.3805 \times 10^{-16} \text{ erg/K}$ (Boltzmann constant)
 $T_o = 273.15 \text{ K}$, freezing point of water

The surface tension of supercooled water is from Hacker (1951) ^[8] for σ_o , $-22.5^\circ \text{C} < T < 27.5^\circ \text{C}$.

$$\sigma_o = 75.6 \text{ dynes/cm} + ((79.2 - 75.6) \text{ dynes/cm}) / (-20^\circ \text{C}) \times T^\circ \text{C} \quad (3)$$

$a_o = 46.6 \times 10^{-16} \text{ cm}^2$ (separate calculation and density of supercooled water is close to 1 g/cc).

$n_s = 3.0656 \times 10^{22} \text{ molecules/cm}^3$ (number density of ice) at 0°C and $a = 2.767 \times 10^{-10} \text{ m}$ at 0°C (atomic spacing of ice).

According to Barnes (1929) [9] there is no change in the structure of ice between 0°C and -183°C , so n_s and a are for supercooling.

$P_{\text{H}_2\text{O}}^* = 0.00605 \text{ atm}$, equilibrium vapor pressure of H_2O at 0°C . To refer to subcooling of water, the Clausius-Clapeyron equation applies:

$P_{\text{H}_2\text{O}}^* = p_o \exp[L_v/R((T-T_o)/T_xT_o)]$ Where T and T_o are in Kelvin. (See Fig 5, from Cantrell, *et al*, for details).

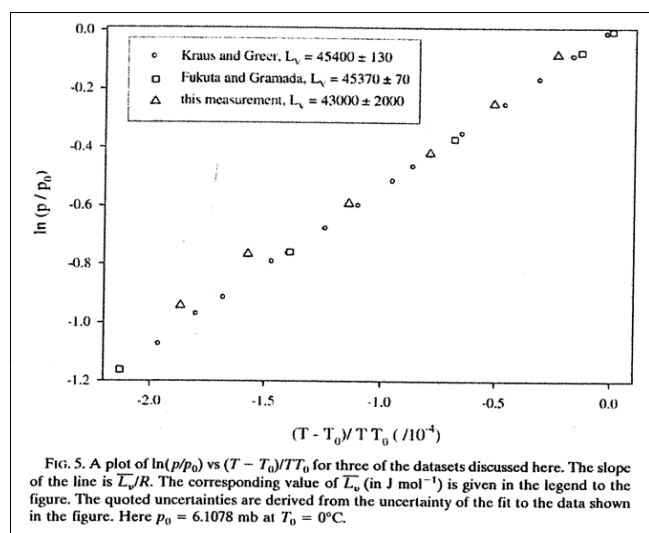


FIG. 5. A plot of $\ln(p/p_o)$ vs $(T - T_o)/T_o$ for three of the datasets discussed here. The slope of the line is L_v/R . The corresponding value of L_v (in J mol^{-1}) is given in the legend to the figure. The quoted uncertainties are derived from the uncertainty of the fit to the data shown in the figure. Here $p_o = 6.1078 \text{ mb}$ at $T_o = 0^\circ\text{C}$.

$p_o = 6.1078 \text{ mb}$ when $T_o = 273.15\text{K}$. From Fig 5, we take the average of three values for L_v .

$$L_v = (45400 + 45370 + 43000)/3 \text{ J/mole} = 44590 \text{ J/mole}$$

(Reference 10)

For Pair, we have the following:

h	Pair
0m	1atm
2000m	0.8atm
7000m	0.4atm
12,000m	0.2atm

So, the equation relating h and P_{air} is the following. Air pressure above sea level can be calculated as:

$$P_{\text{air}} = 101325 (1 - 2.25577 \times 10^{-5} h) \times 5.25588 \quad (4)$$

Where 101325 = normal temperature and pressure at sea level (Pa), P_{air} = air pressure (Pa), h = altitude above sea level (m). (Reference 11).

The calculation has to be done by computer because T occurs a number of times in Equation (1).

Results

It must be mentioned here that cloud seeding needs to be done in the Rocky Mountains that feed the Colorado River. NaCl , AgI , dry ice or even possibly $\text{CH}_3\text{O}-\text{Na}^+$ could be used with monitoring of the rainfall. The distribution of clouds and snow cover exert a major influence on the proportion of light reflected back into space and energy balance. Shell (2018) This means that the forests must be preserved.

Discussion

$$T = D (7.14 \times 10^7) / (k n_s a ((3 k T_o^2/\sigma_o a_o) (P_{\text{H}_2\text{O}}^*/P_{\text{air}}))^{0.69})$$

We need to examine the influences that each part of this Equation (1) has on the undercooling temperature T . To is the freezing temperature of water and k (constant), and n_s , a and a_o are constant as the structure of ice doesn't change from 0°C down to -183°C . As altitude increases, P_{air} goes down, which makes T decline. To calculate the final answer in detail, T occurs in D , σ_o and $P_{\text{H}_2\text{O}}^*$, so a computer is required.

Conclusion

The author has an interest in cloud chemistry and is trained in physical chemistry research. This paper is another effort to explore rain and snow and their effect on the environment.

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