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Effect of Modified Polarizability on Nucleation during Water Vapour Condentation

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ABSTRACT

We have estimated nucleation rate during water vapour condensation by using modified value of polarizability. The effective polarizability increases the Gibb`s free energy, nucleation rate and radius of water nucleus.

1. Introduction

On the condensation of water vapour murino[1] pointed out the effect of external electric field and concluded that under constant temperature a bigger size of drop can be produced in given time since water is strongly polarized medium so polarizability plays an important role in inducing the electric dipole on water vapour molecules.

A polar molecule is affected by the external electric field in two ways. Firstly, it displaces the centre of gravity of protons and electrons so that an extra dipole moment is induced. This is called the electronic polarizability. Secondly, the dipole tends to orient itself, so that the polarizability depends upon the temperature.

The value of polarizability α is modified [2]

$$\alpha_{eff} = \alpha + \frac{p_0^2}{3kT} \qquad \ldots\ldots(1)$$

Where p, k, T are electric dipole moment, Boltzmann constant and temperature respectively.

In an external field the moment induced on a droplet is given by

$$\vec{M} = \vec{E}\, r_w^3 \qquad \ldots..(2)$$

Where $\vec{E}$is the induced electric field and r_w is the radius of water embryo.

In thunder cloud the moment induced on water vapour molecules is

$$\vec{M'} = \alpha\, \vec{E} \qquad \ldots\ldots.(3)$$

Where α is polarizability.

The electric field generated by embryo dipole at a point at distance r_p from embryo is

$$\vec{E} = \frac{3\,(\vec{M}.\vec{r}_p)\vec{r}_p - r_p^2\vec{M}}{r_p^5} \qquad \ldots\ldots.(4)$$

The embryo acquires a critical size due to condensation of water Vapour molecules, called nucleus. Further condensation on nucleus makes a droplet. The rate of change of mass of droplet is

$$\frac{dm_w}{dt} = \rho_v S_n\left(9\,\alpha_{eff}\,\lambda\,E^2 m_w r_w\right)^{1/2} \qquad \ldots\ldots.(5)$$

Where

m_w = Mass of water vapour molecule
λ = Mean free path
E = External electric field
ρ_v = Density of water vapour
S_n = Droplet surface area

The expression for the rate of growth of radius of water embryo has been derived as Singh et al.[3]

$$\frac{dr_w}{dt} = \frac{\rho_v}{\rho_w}\left(\frac{9\,\alpha_{eff}\,\lambda\,E^2}{m_w\,r_w}\right)^{1/2} \ldots\ldots.(6)$$

Where $\rho_w$is density of water.

Integrating above equation with in the limit $r_w = 0$ tor_w^* (critical radius of water nucleus in presence of electric field) and $t = 0$ to $t = \tau$ (relaxation time)

We get

$$r_w^* = \left[\frac{3\,\rho_v\left(\frac{9\,\alpha_{eff}\,\lambda\,E^2}{m_w}\right)^{1/2}\tau}{2\,\rho_w}\right]^{2/3} \qquad \ldots\ldots.(7)$$

The Gibb`s free energy for the formation of critical nucleus is

$$\Delta G_w^* = \frac{4}{3}\,\pi\,\sigma_{w/v}\,r_w^{*2}$$

Where $\sigma_{w/v}$ is surface free energy of water vapour interface.

Pruppacher and Klett (1978)[4] derived the expression for nucleation rate of water and we get

$$\ln J_w^* \propto \frac{\Delta G_w^*}{kT} \qquad \ldots\ldots.(8)$$

In the present calculation we have taken

α = 5 x 10^{-23} cm^3
p_0 =1.81 x 10^{-18}esu
k = 1.38 x10^{-16} ergdeg K^{-1}
ρ_v = 10^{-5}gm cm^{-3}
λ = 10^{-5} cm
m_w =3.0 x 10^{-23} gm
M_w =18
$\rho_{w/v}$ = 72.8 dynes/ cm
ρ_w = 0.996gm cm^{-3}

Table -1

Calculated values of radius (r_w^*), Gibb's free energy (ΔG_w^*) and nucleation rate ($\ln J_w^*$) at electric field E = 5esuand T= 293 K as a function of relaxation time (τ) in water phase

τ μ sec	r_w^* (x 10^{-8} cm)	ΔG_w^* (x 10^{12} ergs)	$\ln J_w^*$
3	21.28	132.76	- 3.28
12	57.32	962.78	-23.79
21	83.44	2040.23	-50.42
30	105.51	3262.74	-80.63
39	125.66	4627.59	-114.365

2. Result and discussion

The computed results for radius (r_w^*),Gibb's free energy (ΔG_w^*) and nucleation rate ($\ln J_w^*$) at electric field E = 5 esu are given in table 1 at temperature T= 273 K as a function of relaxation time (τ). It is clear that with increasing the relaxation time (τ) the radius (r_w^*), Gibb's free energy (ΔG_w^*) and nucleation rate ($\ln J_w^*$) increases very rapidly.

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