Variation of relaxation time of aerosol due to presence of external electric field

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Abstract:

We have calculated the relaxation time of aerosol in the presence of external electric field of 2.0 x 10^4 v/m at a temperature 276 K for different values of super saturation ratio. We conclude that the relaxation time is decreased due to presence of external electric field.

Keywords: Super saturation ratio, Relaxation time, Nucleation rate, Water vapour condensation

Introduction:

Shaw[1] has shown the effect of electrical discharge in nucleation. The effect of electric field on the condensation have been studied by perionl worker[2-4].

Theoretical consideration:

Collins[5] evaluated the relaxation time in absence of electric field as

$$\tau_0 = \frac{9\,\pi\,k\,T(n_w^*)^{2/3}}{{\mu_w^*}^2\,\beta_w\,\sigma_{w/v}} \qquad \text{..........(1)}$$

Where

k= Boltzman constant

$\sigma_{w/v}$ = Surface tension of water vapour surface

β_w = Frequency of collision of molecules per unit area

$$\mu_w^* = 4\,\pi\left(\frac{3\,m_w}{4\,\pi\,\rho_w}\right)^{2/3}$$

Where

ρ_w =Density of water

m_w = molecular mass of water

n_w^* = the no. of water molecules in a critical nucleus

Application of an external electric field induces an electric dipole moment on the embryo of water as well as surrounding water vapour molecules. The vapour molecules experience the external electric field as well as the field produced due to the embryo dipole. The induced moment on vapour molecule is calculated taking in to account the total electric field.

The increase in mass dm_w of the embryo in time dt is

$$\frac{dm_w}{dt} = \rho_v \, S_w \, V \qquad \text{…………(2)}$$

Where

ρ_v = The density of water vapour molecules

S_w = the surface area of water embryo

The velocity of water molecules

$$V = \left(\frac{9\,\alpha\,\lambda\,E^2}{m_w\,r_w}\right)^{1/2} \qquad \text{……………(3)}$$

Where

α = Polarizability Constant

E = Electric Field

λ= Mean Free Path

Now substituting the value V in eq. (2)

$$\frac{dm_w}{dt} = \rho_v \, S_w \, \left(\frac{9\,\alpha\,\lambda\,E^2}{m_w\,r_w}\right)^{1/2}$$

Again expressing in terms of increase in radius with respect to time we have

$$\frac{dr_w}{dt} = \frac{\rho_v}{\rho_w} \, \left(\frac{9\,\alpha\,\lambda\,E^2}{m_w\,r_w}\right)^{1/2} \qquad \text{…………..(4)}$$

Integrating above equation with in the limit $r_w = 0$ to r_w^* (critical radius) and $t = 0$ to $t = \tau$ (relaxation time)

We get

$$r_w^* = \left[3\,\rho_v\,\left(\frac{9\,\alpha\,\lambda\,E^2}{m_w\,r_w}\right)^{1/2} \tau_N/_{2\,\rho_w}\right]^{2/3} \qquad \text{…………..(5)}$$

Substituting the values as

α = 5.56297285 x 10^{-39} m^3

ρ_v = 10^{-2} kg m^{-3}

λ = 10^{-7} m

m_w =3.0 x 10^{-26} kg

ρ_w = 9.999646226 x 10^2 kg m^{-3}

We get

$$r_w^* = [6.12777 \times 10^{-12} \; E \, \tau_N/\rho_w]^{2/3}$$

$$\tau_N = \frac{(r_w^*)^{3/2}\rho_w}{6.12777 \text{ X } 10^{-12} \; E} \qquad \ldots\ldots\ldots\ldots..(6)$$

Under the combined effect of electric field and diffusion the reduced relaxation time τ_{oN} is given by

$$\frac{1}{\tau_{oN}} = \frac{1}{\tau_o} + \frac{1}{\tau_N}$$

$$\tau_{oN} = \frac{\tau_o \, \tau_N}{\tau_o + \tau_N} \qquad \ldots\ldots\ldots\ldots..(7)$$

Table

Calculated values of critical radius r_w^* , τ_o , τ_N and τ_{oN} at T= 276 K and electric field E = 2.0 x 10^4 v/m in water vapour condensation.

S. N.	$S_{v\,w}$	r_w^* x10^{-7} (m)	τ_o (Sec)	τ_N (Sec)	τ_{oN} (Sec)
1	1.001	11.875263525	64.967948987	10.558981494	9.0827916173
2	1.002	5.9405976131	16.258217063	3.7359611338	3.0378876518
3	1.003	3.9623749850	7.2330887041	2.0351222607	1.5882482489
4	1.004	2.9732631786	4.0726712024	1.3228395585	0.9985135446
5	1.005	2.3797957015	2.6091076382	0.9472544594	0.6949485956
6	1.006	1.9841503895	1.8136848192	0.7211390688	0.5159802177
7	1.007	1.7015463151	1.3338291192	0.5726942295	0.4006645081
8	1.008	1.4895930146	1.0222282970	0.4690926038	0.3215402756
9	1.009	1.3247402304	0.8084889629	0.3934171002	0.2646408010
10	1.010	1.1928578078	0.6555261180	0.3361554535	0.2222070932

Result and discussion:

The values of critical radius r_w^* , τ_o , τ_N and τ_{oN} are calculated from equation (5), (1), (6) and (7). We see that under combined effect of external electric field the droplets are nucleated in very less time. This supports the rainguish after lightning.

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