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Properties and Behavior of Cloud Particles

Ratna Sen[1] and Ritu Choudhary Jha[2]

School of Fundamental Sciences, Satya group of institutions,
Palwal Haryana, India

Abstract

We studied the properties and behavior of cloud particles in the atmosphere. As because of surface tension a volume of droplets takes minimum surface and therefore having spherical shapes. The growth of droplets by collision and coalescence has been calculated for an initial cloud. It has been found that collection efficiency increases with radius of the drop and also the relative velocity increases with radius. The super cooling of droplets is discussed according to which cloud droplets do not freeze until temperature of -20̊ C or lower is achieved. A droplet freezes only if it contains a foreign particle, called an ice nucleus. We also have discussed about the hailstone mechanism for the cloud particle growth and precipitation. By cloud seeding concentration of ice nucleus may be possible. We have also studied the discharge of lighting in clouds and the term pilot leader and return stroke are discussed.

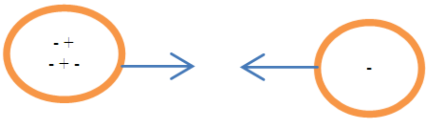
Keywords: Coalescence, collection efficiency, hailstone , pilot leader and return stroke.

1. Introduction

Our atmospheric constituents are classified into two groups: well mixed, and variable. Nitrogen and oxygen, which account for roughly 99% of the atmosphere are the well mixed constituents. These constituents have long residence times they enter and leave the atmosphere much more slowly than the typical time it takes for turbulence to mix them up thoroughly throughout the atmosphere. The most important variable constituent is water vapor. Water is the only atmospheric constituent that can change phase at the typical pressures and temperatures in the Earth’s atmosphere. It can condense to form clouds and precipitate out as rain, and it can evaporate from the surface and from cloud and rain droplets. These are fast processes, so the residence time of water vapor is brief.

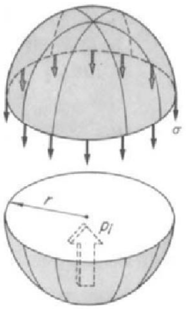
2. Intermolecular Force and Surface Tensionin Droplets

At very small separation the electron clouds of the molecule overlap, strong repulsive valence forces dominant. The forces shown at separation less than r_0 are dominated by the valence repulsive forces .The theory of valence force which is developed from quantum mechanics, predicts that this force is approximatelyan exponential function of distance.Secondly electrostatic contributions may be calculated from coulomb law if the geometrical arrangement and electrical nature are known. The electron in nonpolar molecule is constantly in oscillation so that at certain instant molecule assume a dipole configuration. An induced dipole is created from the adjacent molecule and attractive forces arise between them. In other words we can say at small separation large attractive force exists and it is of great importance in understanding surface properties.



Dipole

Because of surface tension a volume of liquid tends to assume a shape with minimum area-to-volume ratio. Therefore, small masses tend strongly to assume spherical shapes; in the case of larger masses, forces which are mass dependent may distort or destroy the spherical shape. Spherical drops experience an internal pressure due to surface tension which may be calculated
in the following way.



The surface tension force per unit length (o) and the internal pressure force per unit area *(p,)* for a dissected drop of radius *r,*

Imagine a small spherical drop of radius *r* which is divided in half by a hypothetical plane . Surface tension acting across the plane holds the edges of the sphere together; the total force may be expressed by $2\pi r\sigma$where σ represents surface tension or surface energy per unit area. The two halves of the sphere are held apart by the equal pressure forcesexerted normal to the plane surface and given by $\pi r^2 P_i$where $P_i$representsthe internal pressure due to surface tension. For equilibrium between the two forces, the internal pressure due to surface tension is given by

$$P_i = 2\sigma/r$$

The surface tension of pure water at 0° C is about 0.075 N m^{-1} and is very slightly dependent on radius. This equation shows that a droplet of 1µmradius experiences an internal pressure of about 1.5 atm.

3. Homogeneous Condensation

When saturated air is subjected to rapid expansion in the laboratory, the temperature of the air drops and large supersaturation can be achieved. Experiments show that by using air free from foreign particles and ions, the saturation ratio (the ratio of vapor pressure to the saturation vapor pressure over a plane surface of water) reaches about 5 or perhaps more in order for droplets to form from the vapor. From the results it is interpretedthat in the highly supersaturated air random collisions of water molecules result in the occasional formation of clusters of molecules or droplet embryos. If the saturation ratio exceeds the critical value (~5), the embryos continue to grow by condensation, whereas for a smaller ambient vapor pressure, they evaporate. This process is called homogeneousor spontaneouscondensation. Condensation occurs in clean air on negative ions at a saturation ratio of about 4 and on positive ions at a saturation ratio of about 6. These ions are formed by cosmic rays or radioactive decay products striking neutral air molecules. Super saturation in the atmosphere is rarely observed to exceed about one percent, so it is evident that homogeneous condensation does not occur in the atmosphere.

4. Distribution and Properties of Aerosols

Suspended solid and liquid particles (aerosols) are present in the atmosphere in large amount, and their concentration varies by several orders of magnitude with time and in space. Their radius varies from $5 \times 10^{-3}$to 20µm. These particles play crucial roles both in condensation and in the formation of ice crystals. The aerosols participate in chemical processes, they influence the electrical properties of the atmosphere, but in large concentrations they aredangerous and even lethal. Radioactive aerosols may be used as tracers of the air motion but also has its hazardous aspects. Except for areas near industries or other sources, the distributions exhibit remarkable similarity, which may be explained by the physical processes of *coagulation* and *fallout.* If one imagines an initial distribution with equal numbers of particles of every size, the particles of radius less than 10- 2µmquickly become attached to larger particles due to Brownian motion, while the particles of radius greater than 20 µmare sufficiently heavy to precipitate out. Both processes sharply depend upon size. Division according to mass is into three categories: Aitken, large, and giant, is arbitrary but corresponds roughly to differences in technique of observation. *Aitken* nuclei are named after the physicist who first studied the small particles using a counter based on the rapid expansion of a chamber containing saturated air. Expansion produces adiabatic cooling until the Aitken particles act as condensation nuclei; the minute droplets so formed grow almost instantaneously to visible size. The large nuclei, which are smaller in number than the number of Aitken nuclei, can be removed by allowing the larger droplets to settle out.

The Aitken nucleus counter isused for detection of particles with radius less than 0.2µm. Particles from 0.2 to 1µm arecalled largenuclei, this are detected by optical means and have been collected by thermal and electrostaticprecipitation. Particles largerthan 1µm are called giantnuclei,these have been collected on coated slides by impactor.

5. Growth of Droplets by Collision and Coalescence

Herethe growth of droplets bycollision and coalescence with other droplets of different sizes and differentfall velocities is examined.A falling droplet is acted on by the force of gravity and by the frictionor drag force exerted by the air. The downward force due to gravity is expressed by

$$F_g = 4/3\pi r^3(\rho_w - \rho)g$$

Where ρrepresents air density, ρ_w represents water density and rrepresents the radius of the droplet.

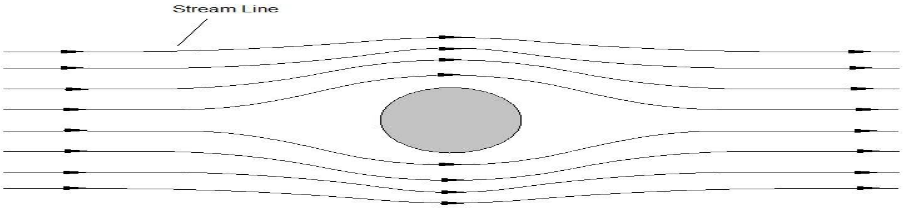
Using stroke's law, the drag force is given by

$$F_d = 6\pi \eta r w_t$$

Where η represents the dynamic viscosity of air and $w_t$the fall velocity of the droplet. Stokes's law holds accurately for droplets of radii less than 50 pm. when the droplet is falling at its terminal (Constant) velocity, the drag force and the force of gravity are equal and Neglecting ρcompared to $\rho_w$the terminal velocity is given by

$$F_g = F_d$$

$$W_t = 2/9\,(r^2 \rho_w g)/\eta$$

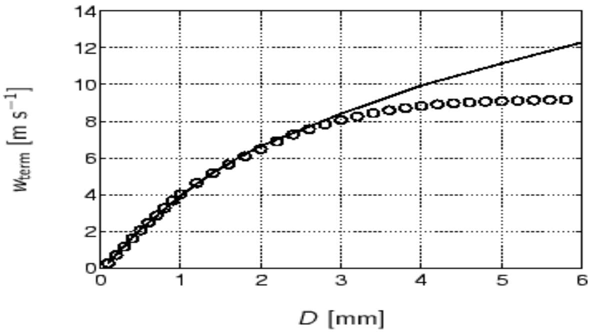


We define the collision efficiency($€_c$) as the ratio of all the small droplets in the volume swept out by the falling drop. The radius of the circle which encloses all droplets which collide with larger drop can be expressed as $(€_c r_0)^{1/2}$,(the radius of droplet is neglected compared tor_0).

Results of calculationsshown as a function of ratio of droplet to drop sizes:

1. $€_c$ is small if ratio is small.
2. If the collecting drops must be of 30µm in radius then the $€_c$ approaches to unity and drop size increases collision efficiency $€_c$ becomes unity.
3. $€_c$ for drop of same size falling with same speed may be exceed unity and they attract each other due to acceleration of air between them.

Not all the droplets that collide with the larger drop adhere to it. The ratio of number of droplets that adhere to the number of collision, called the coalescence efficiency. The coalescence efficiencies are near unity for drop size ratio less than about 0.1, but they fall rapidly as the ratio approaches unity. Coalescence can be enchanced in an strong electric field. The product of collision and coalescence efficiencies is called collection efficiency.it increases with the radius of the drop and the relative velocity also increases with radius. The rate of growth by collection proceeds more and more rapidly as size increases.



5.1 Supercooling of Droplets

The cloud droplets which are cooled to temperatures below 0° C commonly remain as liquid droplets and often do not freeze until temperatures of -20° C or lower is reached. Observations conclude that at temperatures of -14° C, about 20% of clouds contain only liquid droplets 6and at - 8° C about 50% of clouds contain liquid droplets. In the laboratory very pure water droplets can be cooled to aout -40°C before freezing occurs. The formation of ice crystals from supercooled dropletsat this temperature is called homogeneous or spontaneousnucleation. At temperatures above - 40° C a droplet freezes only if it contains a foreign particle, called an ice nucleus. Freezing by an ice nucleus is called heterogeneous nucleation.The growth of molecular aggregate to this critical size increases as temperature decreases. For freezing of a droplet only one aggregate should reach critical size, and therefore probability of freezing increases with volume. The probability of presence of at least one foreign particle increases with volume, so freezing temperature depends on volume.

5.2 The Development of Hailstones

A falling raindrop cannot grow to a diameter greater than about 5mm because at larger sizes surface tension is overcome by the drag force of the air stream and the drop breaks into several fragments. However, if the drop freezes it may collect ice particles and liquid water which may collect ice particles and liquid waterwhich then may freeze, and growth may continue to a very large size. In this way hailstones grow from diameter 5 mm to 10 cm. The largest hailstone recorded in the United States was about 15 cm in diameter. At the center of the hailstones frozen drops usually a few millimeters in diameter are found. Surrounding the centers there are a number of concentric layers of ice of varying density and having different optical properties.By examining the crystalline structure of the hailstone, one can get the information about the concentration, size and impact velocity of the supercooled droplets which produced the hailstone. Sometimes when supercooled droplets are collected by a hail stone realse of latent heat of freezing raises and the surface temperature tends to 0°C and some of water remain in liquid state then there is a formation of spongy hail.The thunderstorm in which large hail occurs are very violent and their structure changes very rapidly so there is no observational data.

5.3 Cloud Seeding

The mechanisms of cloud particle growth and precipitation can be influenced under certain conditions by cloud seeding, in which ice nuclei or condensation nuclei is added to the existing clouds. These ice nuclei vary in concentration and effectiveness.By addition of artificial nuclei at temperature below 0° C it results in nucleation of super cooled droplets so that the ice particles grows and lead to precipitation. This is called overseeding of clouds. As overseedingrealeases latent heat of freezing and gives buoyancy, may result in cloud penetrating a stable layer and growing to greater heights in the unstable air above or in some case the result may be to initate precipitation, which occur by seeding.

The first experiment of cloud modification research, were carried out by Vincent J. Schaefer at General Electric Laboratory in 1946. Ice crystal clouds have been formed by dropping dry ice into air which is saturated with the respect to ice but with respect to water. Bernard Vonnegut discovered that silver iodide crystals are effective in producing ice crystals in water clouds at temperatures below about -4° C. Silver iodide is less effective than dry ice in nucleating ice crystals, whereas dry creates ice crystals in large concentration by silver iodide concentration can be controlled.

6. Conclusion

6.1 The Lighting Discharge

Discharge by lighting may occur between positive and negative centres within the cloudand between the cloud and induced positive ground charge. In a mature thunderstorm there is a largest concentration of charge is associated with the region of strong updraft, The negative cells is at the height of 4 to 9 km and the positive cells at above 10 km. Typically about 20C are discharged in lighting flash and the cloud may be recharged in about 20s.The condition required for spark discharge , when the ion can attain kinetic energy equal to the ionization potential of air molecule. If the potential across a capacitor at sea level is gradually increased, spark discharge occurs in dry air when the potential gradient reaches 30kv cm^{-1}. If droplets are present the breakdown potential is lower and the critical potential in clouds with droplets of 1mm radius is about 10 kV cm^{-1}. Thus the common lightning flash which originates in the negative cloud base, transfers negative charge to the earth.

6.2 Pilot Leader and Return Stroke

The potential difference between convective clouds and ground and within the clouds , as is of the order of 10-100kV/m over most of the volume. However , within the cloud the field fluctuates locally over a wide range as turbulent air motions bring the low-lying mass of positive ions closer or farther from the mass of negative ions. The breakdown potential of about 1MV/m may suddenly develop between the oppositely charged regions. Then there follows a lighting stroke within the cloud , which transfer negative charge downward , neutralizing the small positive charge and charging the cloud base strongly negative. Breakdown potential is not achieved in the column between cloud and ground except immediately adjacent to the negative base. Where breakdown potential is achieved negative charge advances downward and forms an ionized path of 10 cm radius , called the pilot leader. This path grows towards the earth at a rate of 10 to 10 m/s for a distance of roughly 100 m length. Finally there is created a conducting path extending from the base of the cloud to within a short distance above the earth. The potential gradient in the neighborhood of sharp points connected to the earth is now high enough that the breakdown potential is reached , and a positive streamer advances from such a point to meet thepilot leader at a height of 5 to 50 m above the ground. When the pilot leader and streamer meet , earth and cloud are joined by a conducting path roughly 10 cm in radius and up this path rushes the wave of ionizing potential called the “ return stoke “. It advances at about 10 m/s and practically fully ionizes the channel. Now the negative current in the cloud base rushes earthward through the brilliantly luminous channel and discharges roughly the lowest kilometer of the cloud.

Therefore it is suggested that for further research about clouds the better understanding of the physics of thunderstorm and the hail growth is necessary .

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