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On the Behaviour of Water Droplets in the Air at Temperatures below Freezing

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Abstract

When warm water droplets fall suddenly into a cold air region in a cold chamber, they exhibit various interesting behavioures, for example, tracks resulting from rapid evaporation and condensation, disruptions caused by sudden freezing, and sharp winding of tracks in their courses of fall. Those phenomena were photographed and shown in this paper. Such phenomena probably have connection with the condensation trail of aeroplanes.

Introduction

When one of the authors tried to observe freezing phenomena of water droplets in a cold chamber, he found some vertical lines just like cosmic ray tracks as shown in Photo. 1, Pl. I, and also he observed that some water droplets disrupted rarely at a layer below freezing temperature. Later, the authors ascertained that the lines are due to water droplets which jump out from the surface of the water for supplying water vapor. The water used was service water. The size of the droplets ordinarily ranges from 50 to 150 μ. Considering that the lines appear to consist of very small particles, this phenomenon is related perhaps to the rapid evaporaton of the droplets and the subsequent condensation around the course of fall. The behaviour of the droplets is probably connected with the condensation trail. In this paper, the behaviour of the droplets will be shown by semi-microphotographs.

§ 1. Apparatus

The apparatus used is a sort of cold chamber which is cooled from its bottom by dry ice. Fig. 1 is a vertical cross section of

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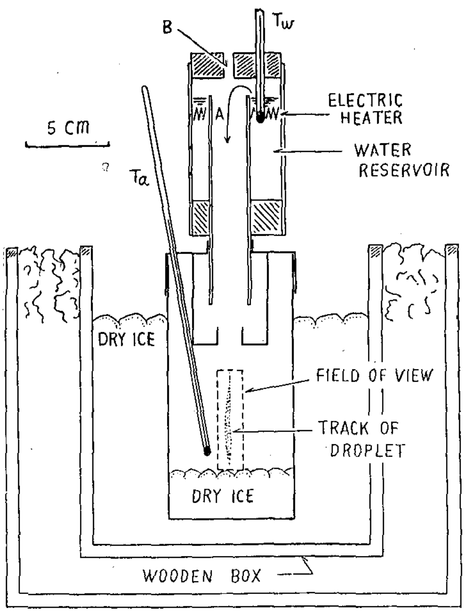

Fig. 1.

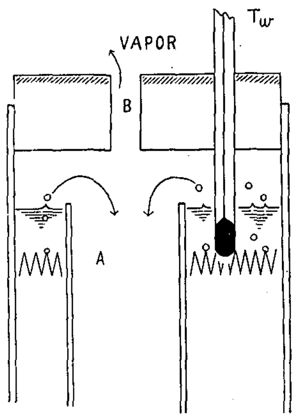

Fig. 2.

the chamber while in Fig. 2 an enlarged representation of the upper part of the chamber is shown. While electrical heat current streams in a water reservoir, several water droplets jump out from the water surface and fall into a hole A at the upper center of the chamber as shown in Fig. 2. Later, it was noted that supplying of water vapor was not necessary to our experiment, therefore, the vapor was driven out from a hole B bored in a cover of the water reservoir. The water droplets which jumped out were illuminated during their fall by two projectors which are very convenient owing to the heat absorbing glasses.

Temperature of the water reservoir and vertical distribution of air temperature in the chamber were measured by thin alcohol thermometers. Hereafter, T_w represents the temperature of the reservoir, and T_a, the air temperature at the height 1 cm above the dry ice surface. In Fig. 3, a distribution of the temperature in the cold chamber is shown, for example. The area enclosed by broken lines in the figure corresponds to the field of view of the camera. One sees in the figure that water droplets are subjected to a veryrapid lowering of temperature ranging from 10 to 15 degrees/cm near the field of view.

§ 2. Tracks made by water droplets

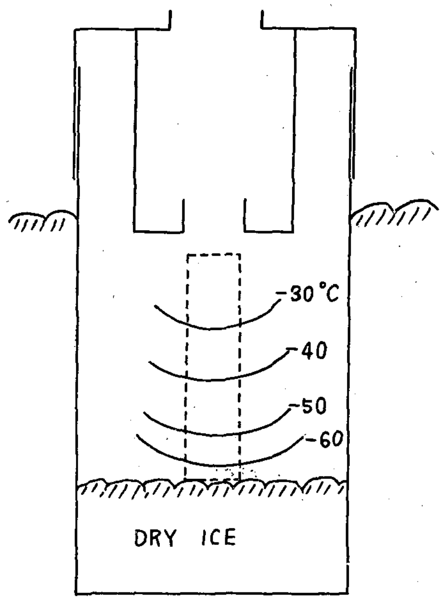

Fig. 3.

The temperature of the water reservoir, T_w, is ordinarily kept at about +90°C ; the temperature of the air at height 1 cm above the dry ice surface, T_a, was varied within the range from 0 to −55°C. In the temperature condition $T_w=90°C$, the lower T_a is, the thicker the track. Photos. 2, 3 and 4 in Pl. I show tracks obtained under conditions that values of T_a were −9.8, −29 and −53°C respectively. As a matter of fact, the width of tracks depends also on the size of droplets. However, water droplets do not always leave tracks. Some unknown factors which are necessary to produce such tracks are still left for future investigation. Such short tracks of a spindle type as shown in Photos. 5 and 6 in Pl. I appear fairly often as if the droplets had disrupted and formed into a group of very small particles. Later, when those tracks appeared simultaneously with ordinary long ones, it was found that the tracks of the spindle type were only comparatively shorter tracks. The short tracks appear usually when the surface of dry ice between the inner metal cylinder and wooden box is lowered, that is, when inclination of temperature near the field of view is steep.

To understand clearly the relation between the tracks and water droplets, it is convenient to show them in one figure. For this purpose, using a bulb shutter, tracks were photographed simultaneously with the droplets which left their tracks ; the operator waits for the droplets to fall keeping the shutter opened, then, at the moment when droplets fall and corresponding tracks appear, he closes the shutter. Photos. 9—12 in Pl. II represent the results thus obtained. Many lines flowing horizontally in the pictures are those produced by fog particles while the shutter is open. In the pictures, one may see the tracks and the course of fall of the corresponding droplets. Although tracks are produced immediately after the droplets fall, the tracks are slightly moved at a lower region. It is noted that in Photo. 12 the tracks are limited to a short length and droplets pass through the tracks. These limited tracks correspond perhaps with the above-mentioned short tracks.

The short tracks are considered to be produced through the following steps.

i) When water droplets fall into a cold region, they evaporate suddenly owing to the large difference between the temperatures of the droplets and the air in the environment.

ii) The vapor produced around the course of droplets' fall begins to condense when the vapor is cooled. This condensed course is a so-called "track."

iii) After the temperature of the droplets becomes low as a result of heat conduction and evaporation, the evaporation from the droplets stops near the dry ice surfac. Thus, short tracks are produced.

A rotating camera to photograph those phenomena is being prepared.

Water droplets do not always leave continuous tracks, but fairly often broken ones as shown in Photos. 13, 14 and 15. Considering that those broken tracks are likely to be produced when T_a is very low, it is considered that phenomenon may be concerned with freezing phenomena of the droplets. Perhaps, droplets seen in the field of view have already frozen.

The track left by droplets is ordinarily very stable. When the track is inclined horizontally by moving air as shown in Photo. 16, the bottom of curved points in the track fall, developing more repidly than the other parts, as shown in Photo. 17. The behaviour is just like that produced in SCHAEFER's[1] seeding experiment in his cold chamber or like that of the smoke of a cigarette when an inversion of air temperature exists in a room.

When a drop drips accidentally from the wall of the holes, it leaves a turbulent track as shown in Photo. 18.

§ 3. Behaviours in freezign of water droplets

When T_a is lower than about $-50°C$, occasionally tracks curve as shown in Photo. 19, Pl. IV. This curving of the tracks is probably due to the curve in the course of the fall of the droplet itself as seen in Photos. 20 and 21. In the latter photograph, two small tracks are seen as indicated by white arrows. Such a loosely curved course of fall as seen in Photo. 22 is often observed. It is usual that several points on the curved course gleam rythmically. Considering those rythmical points of gleaming and the curve of the course of fall, the droplets which left the course have probably frozen already, although it is not yet known why frozen particles curve in the state of fall. Unfrozen droplets of spherical form should fall straight. When water droplets are of nearly the same size with each other, they freeze almost at the same time and begin to gleam suddenly as shown in Photos. 23 and 24. Rarely, they disrupt as seen in Photos. 25 and 26. Those phenomena are naturally expected.

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Reference

1) SCHAEFER, V. J., *Weatherwise*, 8 (1955) 68.

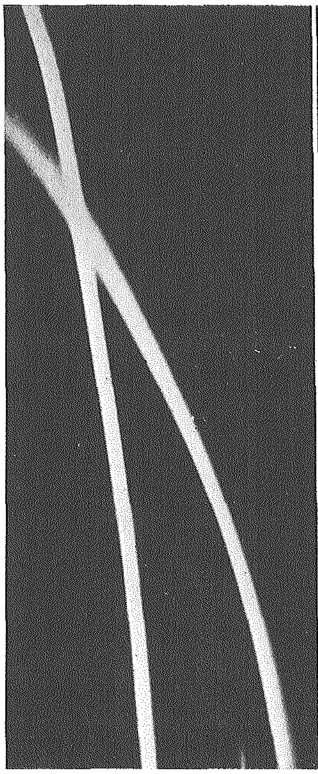

Photo. 1 ×5

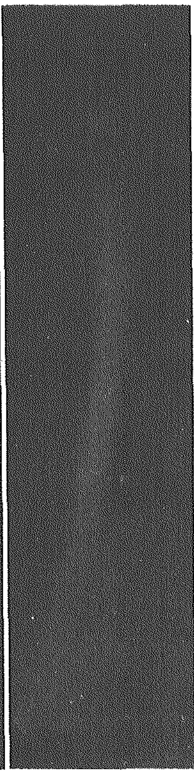

Photo. 2 ×6

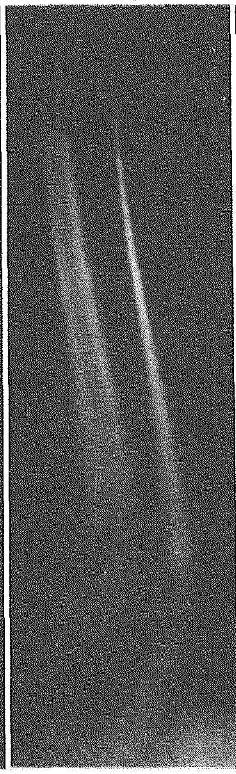

Photo. 3 ×6

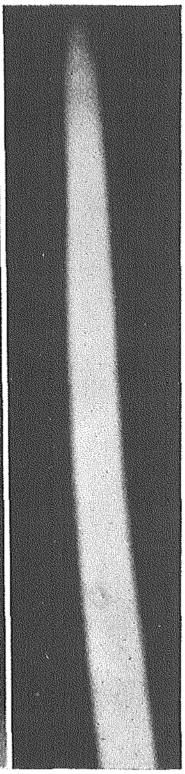

Photo. 4 ×6

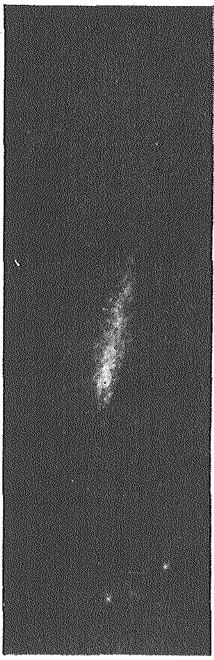

Photo. 5 ×9

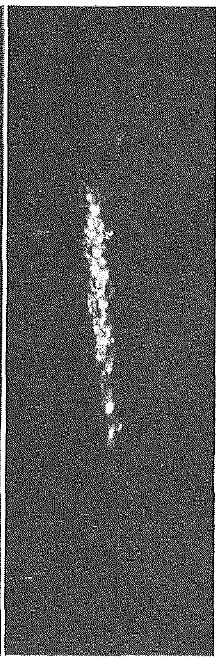

Photo. 6 ×9

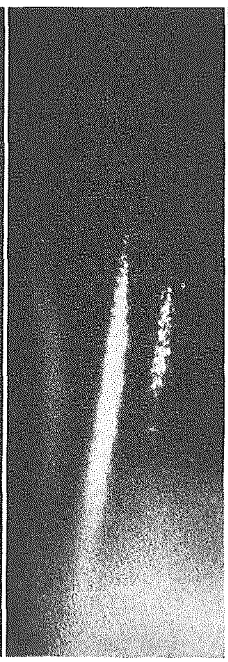

Photo. 7 ×9

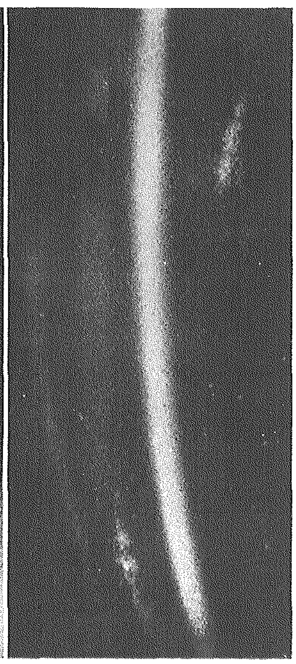

Photo. 8 ×9

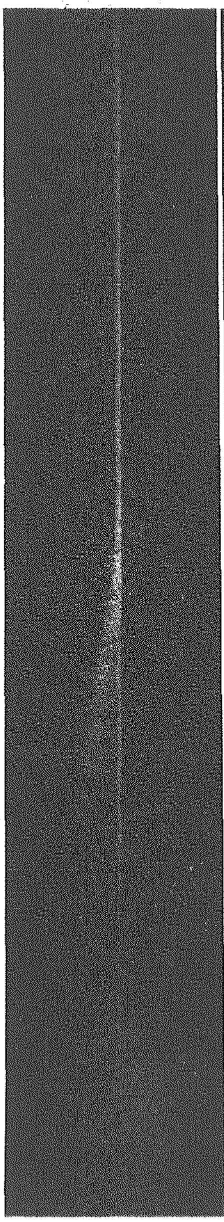

Photo. 9 ×8

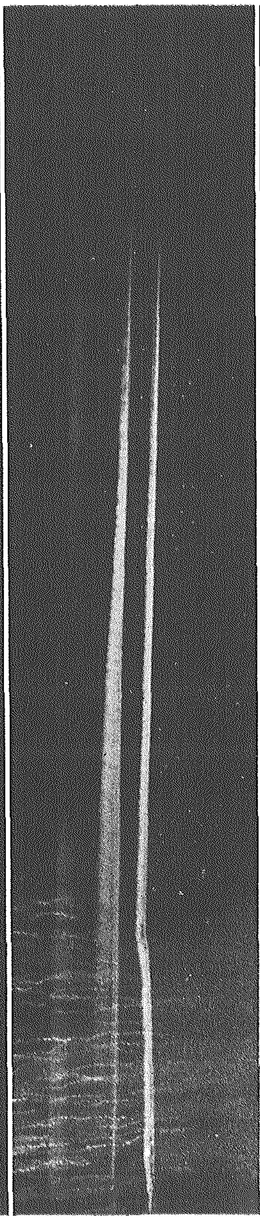

Photo. 10 ×6

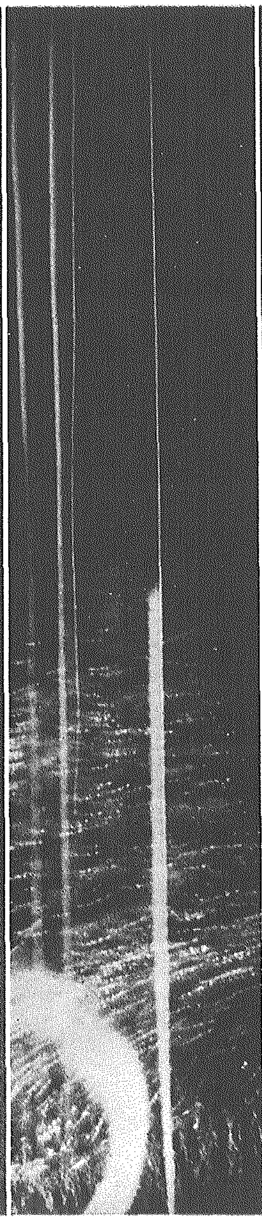

Photo. 11 ×6

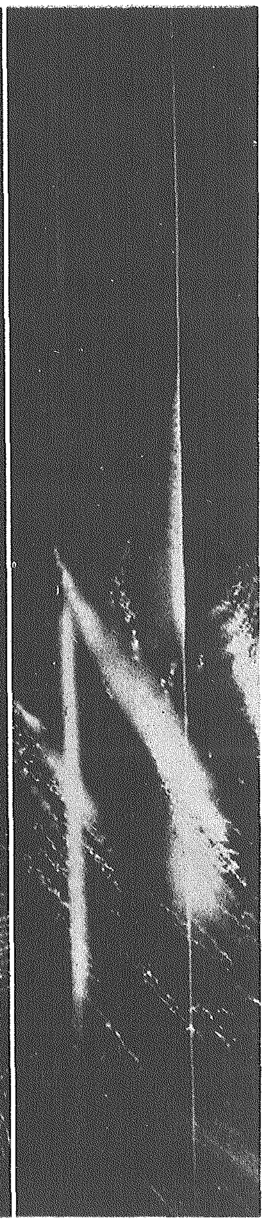

Photo. 12 ×6

Photo. 13 × 7.5

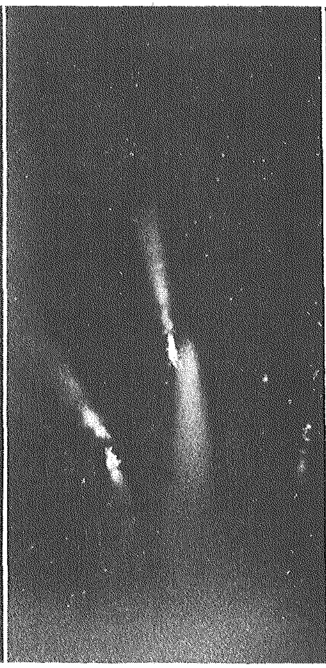

Photo. 14 × 6.5

Photo. 15 × 11

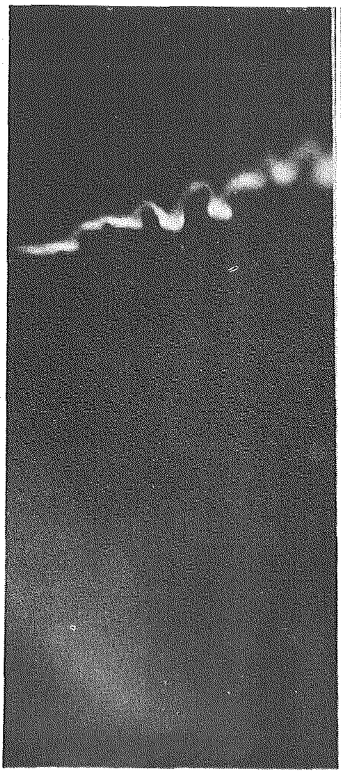

Photo. 16 × 6.5

Photo. 17 × 6.5

Photo. 18 × 4.5

Photo. 19 ×12

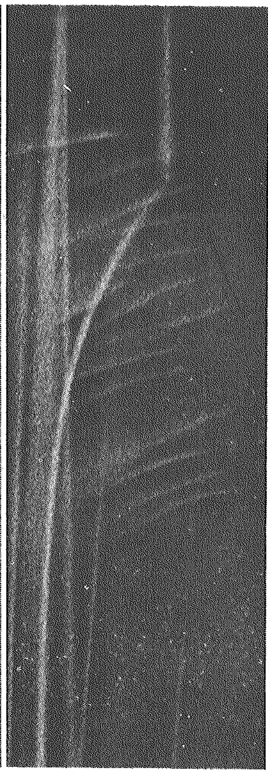

Photo. 20 × 12

Photo. 21 × 12

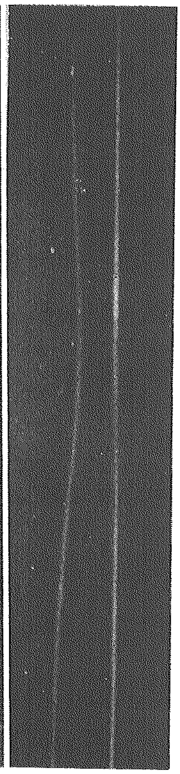

Photo. 22 × 12

Photo. 23 × 7.5

Photo. 24 × 7.5

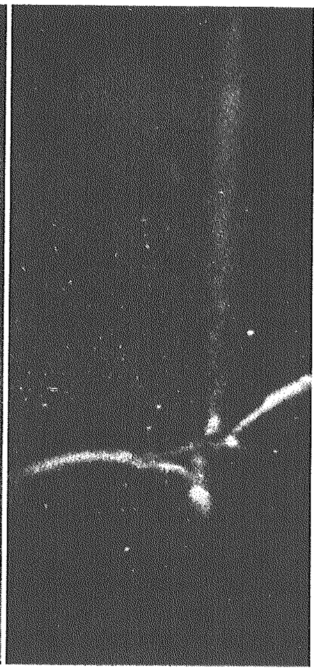

Photo. 25 × 14

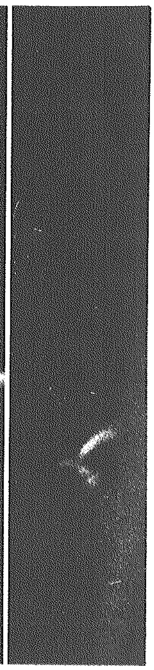

Photo. 26 ×14