NOTES AND CORRESPONDENCE

On the Rebound of Supercooled Droplets Colliding with Ice Plate

By Masahiro Kajikawa

Akita Technical College, Akita, Japan

(Manuscript received 10 December 1974, in revised form 26 February 1975)

1. Introduction

It was pointed out by Mason (1972) that the rebounding and the splashing effect of supercooled droplets from a hail pellet during growth process are very important for the charge separation in thunderstorms.

Carras and Macklin (1973) mentioned on the relationship between splashing and loss of accreted water in dry growth region of hail. Moreover, the experiment of electrification associated with the splashing of droplets was carried out in detail by Shewchuk and Iribarne (1974).

According to the investigation by Aufdermaur and Johnson (1972), charging events due to the rebounding of supercooled droplets colliding with ice pellet at grazing incidence were observed at a rate of about one to ten per 1000 accreted droplets. The droplets leaving ice pellet with separated charge remained liquid. However, it is quite possible that the droplets will start to nucleate on contact with ice pellet and soon freeze under certain different conditions from their experiment.

In the present work, some preliminary experiments were carried out in order to make sure of the possibility of freeze in rebounded droplets and to determine the rate of rebound.

2. Experimental method

Experimental apparatus is shown in Fig. 1 and it was set in a cold room. Water droplets with diameters in the range about 120 to 240 μm were made by an atomizer, which contained distilled or tap water at a temperature about 1°C. The atomizer was earthed to remove electrical influence. The droplets were allowed to fall at terminal velocity through a cylinder (92 cm in length) and collided with an ice plate (about 1 $\times$ 2 cm). It is

Fig. 1. Experimental apparatus.

considered from the calculation due to a method of Hobbs and Alkezweeny (1968) that the droplets were close to thermal equilibrium state with their environment prior to collision. The ice plate was prepared by means of gradual cooling of a laboratory dish, which contained distilled or tap water. The surface of ice plate was smooth and transparent in macroscopic view. The ice plate was fixed on a slender copper rod and was earthed to remove electrical effect, beforehand the collision of supercooled droplets.

The trajectories of droplets illuminated by a stroboscope and a tungsten lamp were photographed with a close up camera. In order to ensure the correspondence of droplets to trajectories

Fig. 2. Supercooled droplets sampled on a glass plate. They are floating in silicone oil.

Fig. 3. Frozen droplets made by the apparatus of Fig. 4.

Fig. 4. Subsidiary apparatus to make the frozen droplets. This is set on the observation chamber in Fig. 1.

Fig. 5. Stroboscopic photographs of rebounding frozen droplets at temperature of -20°C . They were taken with the time interval of 1/100 second.

and to reduce the temperature change of ice plate owing to the latent heat of freezing droplets, the number of colliding droplets was restricted within ten at one time utilizing a slit with a shutter. The diameter of collided droplets was decided by the value of falling velocity, which was calculated from the trajectory of droplets on photographs. The rebounded droplets were almost sampled on a glass plate treated by silicone oil and were observed with a polarizing microscope.

In order to avoid the turbulence of air in the observation chamber, its bottom was slightly cooled by dry ice blocks. Moreover, tiny pellets of ice were placed in it, to approach to the condition of ice saturation as close as possible.

When the ice plate was removed, the fallen droplets on sampling glass are shown in Fig. 2. It was checked by means of polarizing microscope that these droplets are not freezing prior to collision with ice plate. For the purpose of confirming this fact, moreover a subsidiary experiment was performed. The frozen droplets as seen in Fig. 3 were made by apparatus shown in Fig. 4 and the rebounded height of them was compared with the case of supercooled droplets. Fig. 5 is the photographs of rebounding frozen droplets.

3. Results and considerations

The experiments were performed at environment temperature of -10 , -15 and -20°C in the

Fig. 6. Stroboscopic photographs of rebounding supercooled droplets (arrows) at temperature of -20°C . They were taken with the time interval of $1/100$ second.

Fig. 7. Photographs of rebounded droplets taken with polarized light.

impact angle of 90 and about 45 degrees. It may be considered that the temperature of ice plate is approximately equal to that of environment temperature measured with a thermometer of Fig. 1. Examples of rebounding supercooled droplets are shown in Fig. 6 and the right-hand photograph is the case of impact angle of about 45 degree. The photographs of rebounded droplets by polarized light are shown in Fig. 7. As seen from this figure, the rebounded droplets were all frozen. This result is not coincident with that of Aufdermaur and Johnson (1972) who observed the droplets leaving ice pellet remained liquid. It can be considered that the reason of this discrepancy is mainly owing to the difference of impact velocity on the two experiments, in addition to the difference of diameter of droplets. Because, in their experiment the impact velocity of droplets (10 m/sec) is much larger than present

experiment, the contact time between droplet and ice surface may be too less to the growth of ice in supercooled water.

The result of collision of droplets (made by tap water, for brevity, T) with ice plate (distilled water, D) is shown in Table 1. From the standpoint of number of droplets the calculation of rates of rebound (n/N), was restricted to the significant ranges of diameters. It can be seen from the table that the rebound of droplets in the range of 141 to 200 μm , at environment temperature of -20°C , was observed at a rate of about 2 percent.

Under the various conditions of experiments, the rates of rebound were calculated from an amount of data about equal to that of Table 1 and it was summarized in Table 2. When the surface of ice plate was tilted to the direction of collision at angle of almost 45 degree, the rate of

Table 1. The result of collision of supercooled droplets with ice plate. Conditions of experiment are shown in the margin of table.

Diameter of droplet (μm)	Terminal velocity (cm/s)	Number of droplet N	Number of rebound n	$\frac{n}{N} \times 100$ (%)
81—100	16.8— 23.8	1	0	—
101—120	23.9— 32.0	2	0	—
121—140	32.1— 41.2	63	0	0
141—160	41.3— 49.7	152	2	1.3
161—180	49.8— 58.9	95	2	2.1
181—200	59.0— 66.1	52	1	1.8
201—220	66.2— 74.9	18	0	—
221—240	75.0— 83.9	9	0	—
241—260	84.0— 92.2	6	0	—
261—280	92.3—100.0	3	0	—
281—300	100.1—108.0	2	0	—

Temperature.....-20°C

Ice plate.....Distilled water (*D*)Water droplet.....Tap water (T)

Impact angle.....90°

Table 2. The rate of rebounding under various conditions

[illegible]

Table 3. Comparison of the height of rebound of supercooled droplets with that of frozen droplets. Values in parentheses show the cases of rebound angle >10°.

Temperature	−15°C	−20°C	−20°C	−20°C	−20°C	−20°C
Ice plate	<i>D</i>	<i>D</i>	<i>T</i>	<i>T</i>	<i>D</i>	<i>D</i>
Water droplet	<i>T</i>	<i>T</i>	<i>D</i>	<i>T</i>	<i>D</i>	<i>T</i> (Frozen)
32.1—41.2	2.5	—	—	—	—	3.1
41.3—49.7	4.3 (4.2) (3.4) (4.7)	(1.6) (1.5)	3.7 (4.3)	—	(2.4)	4.7
49.8—58.9	5.7 5.8	4.9 (6.4)	5.5	—	3.0	6.9
59.0—66.1	—	8.1	—	6.4	—	10.7
Terminal velocity (cm/s)	Height of rebound (mm)					

rebound was increased considerably. It seems likely that this result suggest the existence of some droplets colliding with ice surface at approximately grazing incidence, as mentioned by Aufdermaur and Johnson (1972).

As the environment temperature rises, the suitable diameter for rebound became smaller in some extent. However, at temperature −10°C, no rebound was observed in the range of diameter 121 to 200 μm. In this temperature condition of ice plate, the existence of liquid-like layer (for example, Nakaya and Matsumoto, 1954 and Hosler *et al.*, 1957) could be considered to be one factor affecting the rebound of droplets. When the ice plate and droplets were made by the water of same nature, the rate of rebound was decreasing somewhat.

Comparison of the height of rebound of supercooled droplets with that of frozen droplets is summarized in Table 3. Because the height of frozen droplets (mean value) is larger than that of supercooled droplets, it was confirmed that the latter was not frozen before the collision with ice plate. Accordingly, it seems likely that the rebounding droplets will start to nucleate on contact with ice plate and leave it with freezing embryo.

4. Concluding remarks

As the supercooled droplets collided with a ice plate at their terminal velocities, the rate of rebound was 2 to 3 percent and the rebounded droplets were frozen. However, the rate was affected by the conditions of experiment as shown in Table 2. This result indicates that the

possibility of rebounding and subsequent freezing of supercooled droplets colliding with rimed snow crystals, although the present experiment is insufficient in the sense that the droplets were larger than that of natural snow clouds.

The phenomenon of freezing of rebounded droplets may some way towards explaining to the large concentration of ice crystals against that of ice nuclei in cumulus clouds. Therefore, it seems necessary to carry out the experiments in various conditions closer to that in natural clouds.

Acknowledgements

The author wishes to thank Prof. C. Magono, Hokkaido University, for making a cold room available for this study. The expense of this study was defrayed from a fund for scientific research of Education Ministry of Japan.

References

- Aufdermaur, A. N. and D. A. Johnson, 1972: Charge separation due to riming in an electric field. *Quart. J. Roy. Meteor. Soc.*, **98**, 369–382.
- Carras, J. N. and W. C. Macklin, 1973: The shedding of accreted water during hailstone growth. *Quart. J. Roy. Meteor. Soc.*, **99**, 639–648.
- Hobbs, P. V. and A. J. Alkezweeny, 1968: The fragmentation of freezing water droplets in free fall. *J. Atmos. Sci.*, **25**, 881–888.
- Hosler, C. L., D. C. Jensen and L. Goldshlak, 1957: On the aggregation of ice crystals to form snow. *J. Meteor.*, **14**, 415–420.
- Mason, B. J., 1972: The physics of the thunderstorm. *Proc. Roy. Soc. London, A*. **327**, 433–466.
- Nakaya, U. and A. Matsumoto, 1954: Simple experiment showing the existence of “liquid water” film

on the ice surface. *J. Colloid Sci.*, **9**, 41-49.
Shewchuk, S. R. and J. V. Iribarne, 1974: Electrifica-

tion associated with droplet accretion on ice. *J. Atmos. Sci.*, **31**, 777-786.

氷板に衝突する過冷却微水滴のはねかえりについて

梶 川 正 弘

(秋田工業高等専門学校)