The Ejection of Ice Splinters by Freezing Droplets of Supercooled Water

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ABSTRACT

Experiments have been conducted in an effort to determine whether small supercooled water drops eject ice splinters when they freeze under conditions which may be representative of those occurring in clouds. An electric field has been used to discriminate between primary and secondary freezing products.

It is concluded that supercooled drops in the radius range 12 to 30 μm may eject ice splinters on freezing. However, the fraction of them that do so is small and the average number of splinters per freezing event is estimated to be about 0.2. This is consistent with the observation of Bader *et al.* (1974).

1. Introduction

The rapid glaciation of some shallow, slightly supercooled clouds (see, e.g., Mossop, 1970) remains a problem requiring satisfactory explanation. Workers in this field have usually sought an explanation in terms of the production of ice splinters either during drop freezing or as a consequence of the riming process, but much of the evidence to date has been contradictory or inconclusive, often as a result of the limitations of experimental technique which have failed to satisfactorily simulate those conditions occurring in natural clouds.

In particular, the study of the freezing of freely falling supercooled drops may be hampered by the requirement to provide an extensive environment in which the drops may be maintained in thermal and solution equilibrium. Hobbs and Alkezweeny (1968) have treated this problem theoretically and derived expressions for the transfer of heat and air to a drop, showing that freely falling drops up to ~50 μm radius will, to a good approximation, be in thermal and solution equilibrium. However, their experiments were hampered by the limited field of view available with their apparatus and the fact that most of their experiments were conducted in an undersaturated environment so that any small ice splinters resulting from the drop freezing process would rapidly sublime. These limitations were not present in the experiment described here.

2. Experimental technique

The apparatus used in this experiment is shown schematically in Fig. 1. A monodisperse cloud of droplets was produced using a spinning top generator which was supplied from two header tanks containing 10^{-4} *M* solutions of sodium iodide and silver nitrate. The mixing of these two solutions produced a suspension of silver iodide in the droplets, of such concentration that the median nucleation temperature ranged between −5 and −7°C, as droplet size decreased from 60 to 20 μm radius respectively (Brownscombe and Thorndike, 1968). A small potential was applied to the needle of the spinning top generator to charge the drops.

Drops from the monodisperse cloud fell through a collimator 0.7 m in height, which was lined with damp blotting paper to minimize the evaporation of the drops. The slit at the top of the collimator was at right angles to the slit at the bottom so that a narrow stream of droplets entered the diffusion chamber. The top slit was also inclined to the horizontal so that any accumulation of water ran off to one side, thus minimizing the possibility of spurious droplets being produced by splashing of water at the bottom of the collimator.

The diffusion chamber was of conventional type, 0.35 m in height and 0.18 m square in section, and surrounded by polystyrene insulation with double-glazed windows for illumination and viewing. To ensure that contamination by carbon dioxide did not occur, the walls of the diffusion chamber were seated in a shallow trough in the aluminum heat sink initially containing water; this froze when solid carbon dioxide was packed around the heat sink. The top plate of the chamber, which held a water reservoir, was sealed with a non-volatile compound. A vertically traversing thermocouple was mounted through the top plate to determine the thermal gradient. Once steady-state conditions had been achieved, the thermal gradient was never greater than 1.5°C cm^{-1} in the viewing region, and usually less than 1°C cm^{-1}, varying only slightly from that indicated in Fig. 2.

Two plane vertical electrodes were mounted 0.12 m apart. These were made of fine mesh gauze which permitted transmission of light through them and caused minimal distortion of the thermal gradient. They were connected to a 0–3 kV power supply. Field strengths of up to 16 kV m^{-1} were used during the experiments, sufficiently low that we may assume that they had a negligible influence on the freezing process. Illumination was provided by a mercury arc lamp mounted behind an asbestos heat shield with a heat-filter glass window, and mounted 30° to one side of the camera axis. A second illumination window was at right angles to the camera axis; light from the mercury arc lamp was reflected onto the droplet stream through this window using a plane mirror. Using this technique it was possible to observe both liquid and frozen droplets to best advantage.

The experimental procedure employed to study splinter production was as follows. The diffusion chamber was seated in its water-filled trough, the water reservoir was filled, and the top plate sealed in position. Solid carbon dioxide was then packed

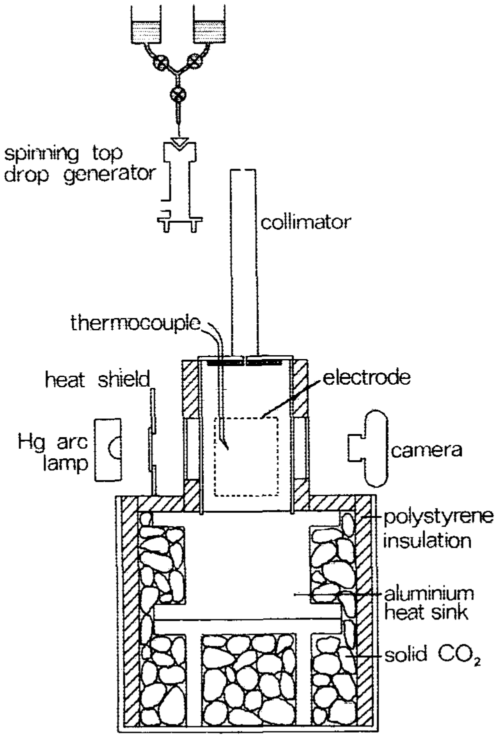

Fig. 1. Schematic diagram of the apparatus.

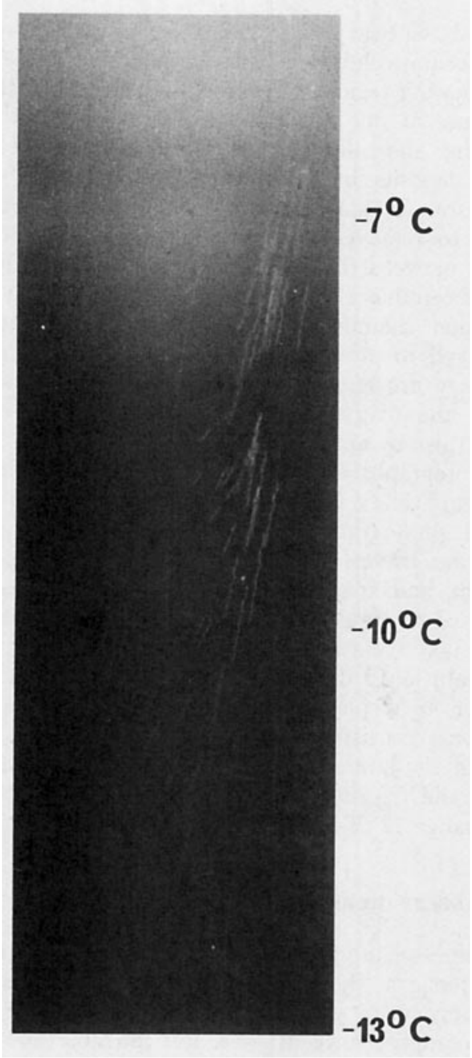

Fig. 2. Streak photograph showing primary products of freezing (to the right) and secondary products of freezing (to the left).

around the heat sink and the apparatus left to reach equilibrium conditions. The temperature gradient over the viewing region was noted, and thereafter the temperature at one particular level was monitored. The viewing and illumination windows were cleared of frost deposits by intermittently blowing air from a domestic vacuum cleaner through a tube containing P_2O_5 to remove water vapor and then through the space between the double glazing. This procedure had no discernible effect on the thermal gradient in the diffusion chamber. The spinning top generator was arranged to provide drops of a suitable size and the mercury arc lamp switched on. Over a period of an hour, the temperature at any level in the chamber would rise by about 1°C.

Photographs were taken of the droplet stream. A 1 s exposure time was usually employed in order to produce streak photographs. Initially a photograph was taken with no traverse field applied to provide a vertical datum, and finally a millimetric graticule was photographed to provide a linear scale. Some 80 photographs were taken, each photograph containing the tracks of typically 5–15 droplets, and with the transverse field chosen to displace the trajectories by the maximum amount consistent with maintaining the droplets within the lateral field of view of the camera. In this way, the freezing of several hundred droplets in the size range 12–30 μm radius was recorded.

3. Observations

Values of the percentage of droplets which produced splinters, or the number of splinters produced per freezing event, were not readily determined from the photographs since it was not possible to identify splinters with their parent drop. Fig. 2 shows the most copious splinter production photographed. Primary product streaks occur on the right; they are generally of consistent length. The splinter streaks on the left are longer in the lower part of the photograph, consistent with the ice particles growing in the high supersaturation.

Of the 80 photographs, which showed the passage of some 500 droplets, of which about 250 would be expected to freeze during their fall through the diffusion chamber, only 8 showed streaks attributable to splinters. The number of splinters observed on these photographs ranged from 2 to 20. Since 90% of the photographs showed no evidence of splinters it would seem reasonable to suppose that those splinters observed were attributable to only one, or at the most two, freezing events. This being the case, the average number of splinters produced per freezing event that produced them is about 8, while the average number of splinters for any freezing event is about 0.2. Analysis was made of those photographs which contained streaks attributable to splinters by simply measuring the length and angular displacement from the vertical of the streak and resolving into vertical and horizontal components to determine the mass and charge of the particles.

The analysis of such a photograph which showed five splinter streaks yielded a probable primary freezing product of between 16 and 18 μm radius, carrying a charge of approximately 2×10^{-3} pC. The five splinters were all of about 12 μm radius and carried charges ranging from 2 to 5×10^{-4} pC. The size of the splinters when photographed would undoubtedly be greater than their size at ejection, but one would not expect their charge to vary significantly during this period of growth. The relatively high charge on the splinters, in comparison with that on the primary freezing product, augments the suggestion that only a few particles might be produced per splintering event. The charge on the splinters was always the same sign as the charge initially on the parent droplets.

In conclusion, it would appear that production of ice splinters by the freezing of droplets in the size range 12–30 μm radius at temperatures between -5 and -7°C, freely falling through a supersaturated environment with a low thermal gradient, occurs for only a very small fraction of freezing events, producing approximately 0.2 splinters per freezing event. This is consistent with the observation of Bader *et al.* (1974) who detected sub-micron ice fragments of radius >0.15 μm using a Pollak condensation nucleus counter, that the average number of splinters ejected when drops of mean volume radius 15 or 21 μm were frozen was less than about 0.3 per drop. It seems probable that those freezing events which do result in splinter production yield only a few splinters.

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