

# UNITED STATES PATENT OFFICE

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## METHOD OF CRYSTAL FORMATION AND PRECIPITATION

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1 This application is a continuation-in-part of  
our earlier application Serial No. 725,156, filed  
January 29, 1947, and later abandoned.

The present invention comprises a process  
whereby crystallization in whole or in part is  
caused in supersaturated vapor-containing gases  
and supercooled liquids. It relates in particular  
to the development of ice crystals in aerosols com-  
prising supercooled water droplets, as, for ex-  
ample, supercooled natural atmospheric clouds in  
which snow crystals do not form even though  
the clouds have assumed a temperature below 0°  
C. and even as low as -35° C. or lower, for  
example, -38° C.

As a consequence of our invention, crystalliza-  
tion may be effected in supercooled liquids, or in  
gases containing a vapor which is supersaturated  
with respect to the solid state. For example, by  
means of our invention, ice crystals may be  
formed in a supercooled cloud or in an air mass  
supersaturated with regard to ice, or in super-  
cooled liquids.

In accordance with our invention, foreign  
nuclei of definite crystalline structure are brought  
into contact with the supercooled or supersatu-  
rated component, e. g., supercooled liquids, super-  
saturated vapors, etc., which preferably should be  
at a temperature several degrees below the tem-  
perature at which the gaseous or liquid phase is  
in equilibrium with the solid phase. For example,  
in the case of supercooled water, e. g., supercooled  
water droplets, the temperature of the said super-  
cooled water should preferably be at least as  
cold as about -4° C. or lower. The foreign  
nuclei which are introduced should have a space  
group and unit cell dimension similar to the solid  
form of the liquid or vapor which it is desired to  
crystallize.

For example, we have found that crystalliza-  
tion in whole or in part of a mass comprising  
supercooled droplets of water can be effected by  
the introduction of minute particles of silver  
iodide at a temperature of about -4° C. and  
below. In this case, the particle size of the silver  
iodide is of the range of from about 1 to 1000  
microns. Smaller sizes of the silver iodide  
crystals are also effective for causing crystalliza-  
tion at temperatures below -4° C.

Thus, particles of silver iodide as small as 0.01  
micron may advantageously be employed. In this  
smaller size range, it appears that the tempera-  
ture at which these particles become active  
centers for crystallization is somewhat lower, for  
example, about -8° C., than that at which the

2 larger crystals of silver iodide will cause forma-  
tion of ice crystals.

The foreign nuclei which are introduced into  
supersaturated air containing water vapor or  
clouds made up of minute droplets of supercooled  
water for the purpose of initiating crystalliza-  
tion preferably have a hemimorphic hexagonal  
crystalline structure similar to that of ice crystals.  
In particular, finely divided silver iodide and  
finely divided wurtzite (ZnS) have been found to  
be effective for this purpose. Various other  
minerals having the aforementioned crystalline  
structure may be similarly employed in a finely  
divided state to initiate crystallization, namely,  
zincite (ZnO), nephelite (NaAlSi<sub>3</sub>O<sub>8</sub>) and apatite  
[Ca(FCl)Ca<sub>4</sub>(PO<sub>4</sub>)<sub>3</sub>].

One effective method of introducing silver  
iodide nuclei comprises feeding a string of com-  
bustible material, e. g., cotton, coated with silver  
iodide into a high temperature flame, for example,  
an oxyhydrogen torch. Simultaneously, a jet of  
compressed air is blown over the flame, without,  
however, extinguishing it, thereby cooling and di-  
luting the gas containing volatilized silver iodide  
and resulting in the dispersion of extremely small  
silver iodide particles, e. g., as low as 0.01 micron  
in size, or smaller, in the aforementioned crystal-  
line form.

We have found that the introduction of foreign  
nuclei of the designated crystalline structure, for  
example, silver iodide particles, may be varied.  
Thus, we have introduced silver iodide crystals  
directly into an atmosphere supersaturated with  
water vapor with respect to ice, thereby causing  
precipitation of the water as ice crystals. In  
another instance, we have found it useful to  
generate smokes comprising minute particles of  
silver iodide and introducing these smokes into  
the atmosphere outside the supersaturated region,  
whereby in the course of time these foreign nuclei  
eventually find their way into supersaturated  
atmospheres by virtue of natural mixing caused  
by movement of the atmosphere.

The present invention of causing the formation  
of crystals by the introduction of foreign nuclei  
possesses definite advantages over a process of  
introducing seed crystals of the component to be  
crystallized, e. g., ice crystals in the case of super-  
cooled water. Sources of minute foreign nuclei  
suitable for causing crystallization can be stored  
and introduced under conditions adverse to the  
storage and introduction of crystals of the com-  
ponent to be crystallized. For example, if it  
should be desired to produce crystallization of a  
supercooled atmospheric cloud, it is possible to

introduce foreign crystallization nuclei, such as herein enumerated under conditions at which ice cannot exist. Silver iodide particles, for example, if introduced into the atmosphere, will become widely distributed and will be available to cause ice precipitation when they come into contact with supercooled clouds or regions supersaturated with water vapor with respect to ice.

When this invention is employed in connection with naturally occurring clouds in the sky, the greatest numbers of crystallization centers are initiated in the vapor phase of the said clouds. This initiation of crystallization can also take place in regions comparatively free of supercooled water droplets where there exist essentially only vapors supersaturated with respect to ice.

It will, of course, be apparent to those skilled in art that in the case of introducing foreign nuclei of the designated crystalline structure into or within the neighborhood of naturally occurring clouds of supercooled droplets, the type of precipitation which reaches the ground will depend on the temperature conditions existing below the cloud. Thus, warm temperatures are conducive to the formation of rain while temperatures closer to the freezing point of water are conducive to the maintenance of the original snow crystalline state, and thus there is obtained a fall of snow to the ground, with the crystals comprising the snow being identical in configuration and latticework to the crystals produced by nature itself.

By the practice of our invention it has been found possible to disperse and precipitate supercooled clouds. For example, dangerous icing conditions adjacent airports and airplane routes can, in many cases, be satisfactorily removed. In addition, weather conditions over certain areas may be controlled by causing these foreign nuclei to mix with or to be injected into naturally occurring clouds, thereby precipitating the supercooled droplets either in the form of snow or rain depending on the temperature conditions existing below the clouds. Furthermore, territorial visibility which is obscured from the air by cloud formations may be improved by causing precipitation of the obscuring clouds in whole or in part. By means of our invention, the harmful effects of hail storms can be ameliorated or eliminated by injecting silver iodide particles into cloud formations thus increasing the number of potential hail nuclei.

In a copending application Serial No. 3,545, filed concurrently herewith by Vincent J. Schaefer, the said application being a continuation-in-part of his earlier application Serial No. 725,155, filed January 29, 1947, and later abandoned, are described other means whereby crystallization in supersaturated atmospheres or in supercooled aerosols may be caused to take place. Included in such means is the introduction of various cooling means capable of reducing the temperature of portions of the supercooled or supersaturated media, for example, particles of solid carbon dioxide, liquid carbon dioxide, liquid oxygen, etc.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. The method of causing crystal formation in a mass having a temperature below  $-4^{\circ}$  C. and being selected from the class consisting of supercooled water droplets and water vapor supersaturated with respect to ice, which method comprises introducing into said mass crystals of a material foreign with respect to said mass and having a space group and unit cell dimensions

closely approximating that of the solid form of said mass.

2. The method of causing crystal formation in a mass having a temperature below  $-4^{\circ}$  C. and comprising supercooled droplets of water, which method comprises introducing into said mass foreign solid particles having a hemimorphic hexagonal crystalline structure, thereby causing crystallization of the water in the aforementioned droplets.

3. The method of causing crystal formation in a mass having a temperature below  $-4^{\circ}$  C. and comprising supercooled droplets of water, which method comprises introducing into said mass minute particles of silver iodide, thereby causing crystallization of the water in the aforementioned droplets.

4. The method of causing crystal formation in a gas having a temperature below  $-4^{\circ}$  C. and comprising water vapor supersaturated with respect to ice, which method comprises introducing into the said gas crystals of silver iodide, thereby causing crystallization of the vapor in the aforementioned gas.

5. The method of causing ice crystal formation in a natural atmospheric cloud which is supercooled to a temperature below  $-4^{\circ}$  C., which method comprises introducing into the said cloud foreign solid particles having a hemimorphic hexagonal crystalline structure, thereby causing the formation of minute ice crystals.

6. The method of causing crystal formation in a mass having a temperature below  $-4^{\circ}$  C. and comprising supercooled droplets of water, which method comprises introducing into said mass particles of zinc sulfide, thereby causing crystallization of the water in the aforementioned droplets.

7. The method of producing rain from a natural atmospheric cloud which is supercooled to a temperature below  $-4^{\circ}$  C. and which comprises a mass of supercooled water droplets suspended in air over an area having a temperature at least equal to that required to melt snow crystals, which method comprises introducing into the said cloud particles of silver iodide whereby myriads of ice crystals are formed and are precipitated as rain upon falling into the atmosphere underneath said cloud.

8. The method of causing ice crystal formation in a natural atmospheric cloud which is supercooled to a temperature below  $-4^{\circ}$  C., which method comprises introducing into the said cloud foreign solid particles comprising crystals of silver iodide, thereby causing the formation of minute ice crystals.

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