Snow Crystal Growth in Detail

What you see in a snow crystal growth chamber demonstrates a lot of physics. In a nutshell, water evaporates from the wet sponge and diffuses through the air in the bottle. When the water vapor mixes with the cold air in the lower part of the bottle, the air becomes supersaturated. This means that the water vapor will condense as ice onto any convenient object. Thus ice crystals will form on the string and on the walls of the bottle. This apparatus, warm on top and cool on the bottom, is called a diffusion chamber. Now let's look at it in more detail.

Saturated Air

If you take a container, add a bit of water, and close the top, the air in the container soon becomes saturated with water vapor. Saturated air has a relative humidity of 100 percent, and is the equilibrium state whenever there's lots of water around. So when it's raining, or foggy, the humidity of the air outside is close to 100 percent.

Supersaturated Air

In the growth chamber, we create supersaturated air, which has a relative humidity of over 100 percent (in fact it's around 200 percent). In physics, we call this a non-equilibrium state, or a metastable state. Left to itself, a box of supersaturated air will not stay supersaturated, since water or ice will condense onto the walls of the box, and the humidity will drop to 100 percent (the equilibrium or stable state). Supersaturated air is made all the time in the atmosphere (typically when warm, moist air mixes with cooler air), and is responsible for rain and snow.

Supersaturated air condenses into water droplets if the temperature is above 0°C, and condenses to ice crystals (snow) if the air temperature is below 0°C. Note that snow crystals are not just frozen water droplets. Rather they are crystals that grow in supersaturated air that is below freezing.

Nucleation

Interestingly enough, supersaturated air doesn't automatically condense to produce droplets of rain (or snow). This only happens when there is some nucleation site on which condensation can occur. (This is why we call supersaturated air a metastable state—it's not stable, but it can hang around for quite a while.)

The reason for this is that very tiny droplets of water (or ice), just a few hundred molecules or so, have a higher vapor pressure than bulk water (or ice). The molecules in such small droplets aren't bound very strongly, which means they come off easily. This is the same as saying that they have a higher vapor pressure. If such small droplets form in supersaturated air, they don't grow, but just evaporate away. If a large droplet forms, it will grow—but large droplets can't just appear spontaneously out of thin air.

In our growth chamber, we provide a string to nucleate ice crystal growth. On a microscopic scale, there are scratches and other imperfections on the string. Even individual water molecules can bind to these imperfections. Once we get a small ice crystal started, it will continue growing.

There are lots of dust particles in the atmosphere, and these make dandy nucleation sites. Rain droplets and snow crystals usually each contain a dust particle on which the growth gets started.

Diffusion

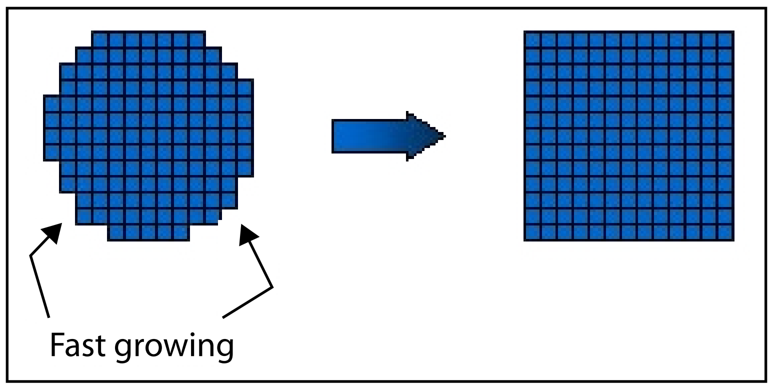
In your growth chamber, the top is warm and the bottom is cool. Since warm air is lighter than cool air, the air in the chamber doesn't undergo convection. The air at the top of the chamber becomes saturated with water vapor because it is right next to the moist sponge. At this point, the humidity is 100 percent. Diffusion happens because the air and water molecules are all moving and colliding with one another, which mixes things up on a microscopic scale. If you open a bottle of perfume in a still room, or put a drop of food coloring in a glass of still water, it is also diffusion that does the mixing.

In our growth chamber, diffusion causes the water molecules to diffuse down from the top. As they diffuse down, they mix into a region where the air temperature is much lower. This is like taking saturated air and cooling it down, with the result that the air becomes supersaturated so ice crystals can form.

Faceted Crystal Growth

Why do ice crystals form facets? It is because of the molecular structure of the ice crystal. If we take an ice crystal and cut it in some random direction, the resulting surface will typically be quite rough on a molecular scale, and the molecule-sized kinks will be very attractive to water molecules in the vapor. Thus the ragged surface will grow fast in supersaturated air. However, if we cut the crystal along a special plane—one of the crystal facets—then the resulting surface will be very smooth, without any molecule-size kinks. Molecules in the vapor phase don't stick well to such a smooth surface, so it tends to grow much more slowly than a ragged surface.

So now consider starting with a spherical ice droplet. Wherever the surface is ragged, the crystal will grow rapidly, but along the facets the crystal will grow slowly. The ragged surfaces fill in, leaving nothing but faceted surfaces. We're soon left with a slow-growing faceted crystal, as observed.



Phase Diagrams

Why does water ice melt into a liquid, while dry ice turns into a gas? The two materials are really not so dissimilar, as can be seen in their phase diagrams. Both have solid, liquid, and gaseous phases, which occur at different temperatures and pressures. However, at a pressure of one atmosphere, which happens to be where we live, dry ice can only exist in the solid or gaseous phases; liquid CO_2 only exists at higher pressures. So water ice is wet, and dry ice is dry. Why the phase diagrams look like they do is of course a deeper question, since that depends in detail on the interactions between molecules.