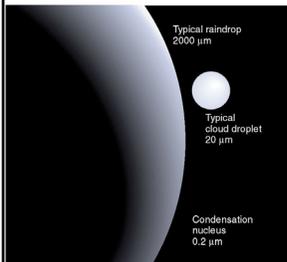


Chapter 8, Part 1

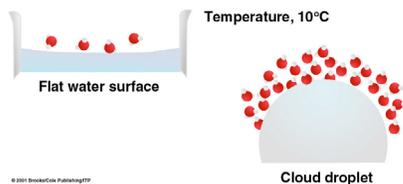
Precipitation Processes

How do droplets grow larger?



- Cloud contain water droplets, but a cloudy sky does not always mean rain.

Cloud Droplets in Equilibrium



- In equilibrium water molecules leaving the droplet are balanced by water molecules entering the droplet.
- This occurs at the saturation or equilibrium vapor pressure.
- More water molecules are needed for a curved surface.

Droplet Growth

- When air is saturated with respect to a flat surface, it is unsaturated with respect to a curved droplet of pure water.
- The air must be supersaturated (>100% humidity) for the droplets to be in equilibrium or grow.

Cloud Condensation Nuclei

- With hygroscopic nuclei such as salt particles condensation can occur below 100% humidity.
- This reduces the equilibrium vapor pressure (solute effect).

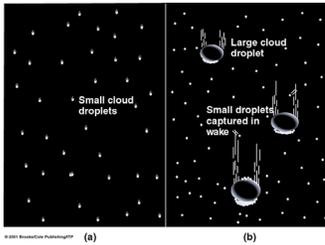
Droplet Growth in a Cloud

- Condensation begins below 100% humidity because of condensation nuclei.
- As the humidity approaches 100%, the larger droplets grow more rapidly.
- This acts to reduce the humidity. An equilibrium is reached between water vapor leaving the droplets and entering them.

Droplet Growth and Rain

- The cloud is composed of many small droplets – too small to produce rain because they fall slowly and evaporate in the dryer air below the cloud.
- How do we get rain?
 - Collision-coalescence process
 - Ice-crystal (Bergeron) process

Collision and Coalescence



- Exists in relatively warm clouds with tops warmer than -15°C (5°F).
- Larger drops collide with smaller ones and grow.

Terminal Velocity

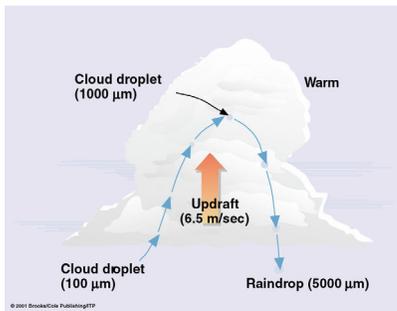
- The speed of a falling droplet increases until the air resistance equals the pull of gravity.

Diameter in μm	Terminal Velocity (m/s)	Type of Particle
0.2	0.0000001	Condensation nuclei
20	0.01	Typical cloud droplet
100	0.27	Large cloud droplet
200	0.70	Large droplet or drizzle
1000	4.0	Small raindrop
2000	6.5	Typical raindrop
5000	9.0	Large raindrop

Droplet Size

- Larger droplets overtake smaller ones.
- The size of the rain droplets will depend on
 - Range of droplet sizes
 - Cloud thickness
 - Updrafts in the cloud
 - Electric charge and field in the clouds

Example of Droplet Growth

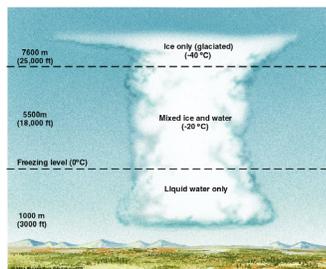


Ice-crystal (Bergeron) process

Ice

Water and Ice

Water



- Important in middle and high latitude cold clouds where the temperature is well below freezing at the top of the clouds.

Water and Ice in Clouds

- Lower part of cloud below 0°C contains water only.
- Even as temperature falls below 0°C the cloud is still made up mostly of supercooled water droplets.
- Only at very cold temperatures, -40°C, does the cloud become mostly composed of ice (glaciated).
- Why?

Freezing

- Large bodies of pure water freeze at 0°C.
- This is done without the benefit of nuclei (homogeneous freezing) by producing small ice particles called ice embryos.
- Small ice embryos form below 0°C, but tend to break apart.
- Only far below freezing (-40°C) will the ice embryo grow to a critical size for even the smallest cloud droplet.

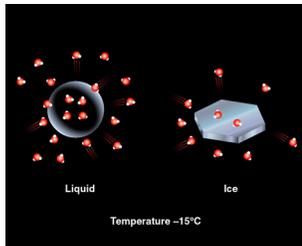
Ice Nuclei

- Ice forms on ice nuclei just as water droplets form on condensation nuclei.
- The number of ice-forming nuclei is small compared to condensation nuclei, but does increase as the temperature decreases.
- Deposition nuclei – water vapor goes directly to ice.
- Freezing nuclei – promote freezing of supercooled liquid, including contact freezing when supercooled droplets collide with them.

Liquid Droplets and Ice Crystals

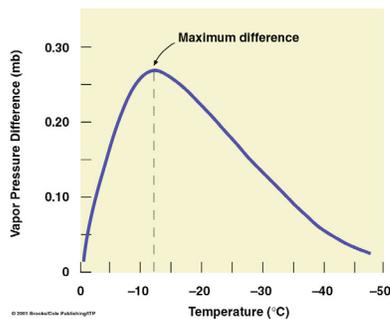
- Cloud droplets freeze, but only at low temperatures.
- Ice nuclei not plentiful.
- Thus, in the subfreezing air of a cloud supercooled droplets and ice crystals coexist.

Equilibrium over Water and Ice



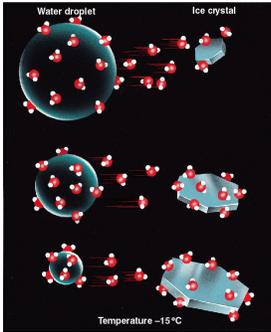
- In equilibrium just as many water molecules leave as enter. (Also called saturation.)
- More water molecules are needed for equilibrium over water than over ice.

Vapor Pressure over Water & Ice



- Another way to say this is that the vapor pressure is greater over supercooled water than over ice.

Ice-Crystal Process



- Thus, water vapor will go from the water droplets to the ice crystals, causing the ice crystals to grow larger at the expense of the water droplets.

Accretion



- Accretion – falling ice crystals freeze supercooled droplets on contact. (riming)
- The icy matter that forms is called graupel.

Secondary Ice Particles



- Falling ice particles collide and fracture creating tiny ice particles.
- This can lead to a chain reaction creating many ice crystals.

Aggregation

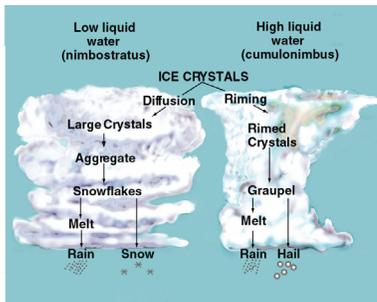


- Falling ice particles may collide and stick together.
- The resulting snowflakes may either melt or reach the ground frozen.

Ratio of Ice to Water

- For ice crystals to grow large enough to produce precipitation, there must be many more water droplets than ice crystals (100,000 to 1 or 1,000,000 to 1).
- Too few ice crystals will not yield much precipitation.
- Too many ice crystals will make the resulting droplets too small.
- Process proposed by Wegener, Bergeron, and Findeisen.

Summary of Ice-Crystal Process



Cloud Seeding

- Inject small particles that act as nuclei.
- Need clouds with too low a ratio of ice crystals to droplets.
- This is frequently not the case because a typical cold cloud has an ice to water ratio of 1:100,000.
- Silver iodide is used.

Summary

- There are two primary processes by which precipitation is created from clouds.
- Collision-coalescence – faster falling larger droplets collide with smaller ones and grow.
- Ice-crystal – ice crystals grow at the expense of supercooled water droplets and then fall.
