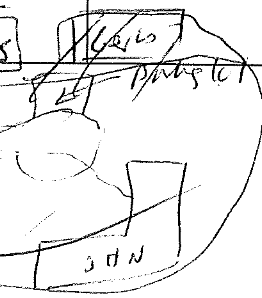
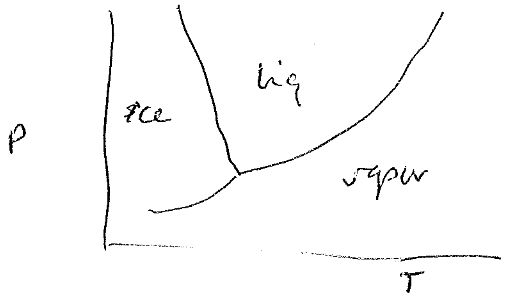
Field trip : ~~Admin~~ bldg parking lot 40 St



blackboard again today

phase diagram.



Interpretn of this diagram is straightfwd & unambiguous if the system consists only of water in its various phases, so the only gas is water vapor. However, it can also be used for processes occurring in the atmosphere and in snow on Earth's sfc, where other gases are also present, if we're careful about what the pressure axis means.

~~what~~ For ice/liquid line, p = total pressure

For {ice/vapor, liquid/vapor} p = partial pressure of w.v. only.

(presence of other gases has only very minor effect on liquid-vapor equilibrium; ~~relevant~~ to the extent that they dissolve in the liquid)

?s about phase diagram?

Formation of snow in the atmosphere

1. formation of water droplets from vapor
2. freezing of water droplets into ice xls
3. growth of ice xls.

} "cloud physics"

Snow xls form mostly by freezing of water droplets
So first consider how water droplets form, then how they freeze

Clouds form when air is "supersatd".

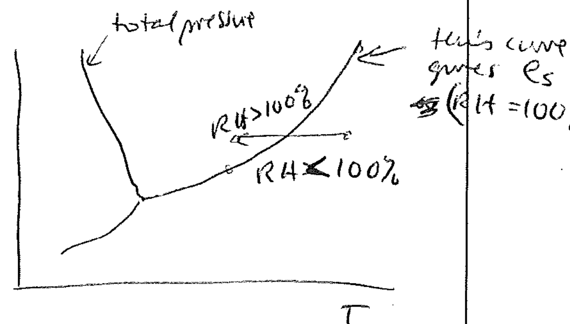
$e \equiv$ vapor pressure
$e_s \equiv$ equilibrium v.p. ("saturation" v.p.)

relative humidity

$$RH \equiv \frac{\text{v.p.}}{\text{satn v.p.}} = \frac{e}{e_s(T)}$$

(0.0→1.0, or 0%→100%)

By coolg will become supersatd



By coolg a parcel of air: e_s decreases so RH increases.
The usual way is by risg of air.

Risg air cools by expansion.

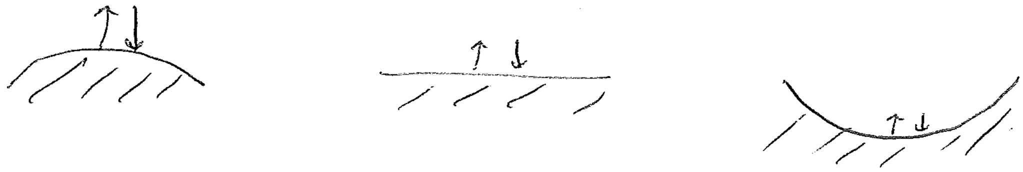
Reasons for risg air given in Aval Hbk readg asgt for today.

1. synoptic storms: risg air in regions of low pressure
2. convective storms: (cu clouds)
3. "orographic" ~~precipitn~~ lifting: air rises over obstruction.

This is why ppth ↑r in mtns than in surrg plains
& ↑r on windward slope than on lee slope

But if we're forming a water droplet from vapor, this phase-diagram is not quite appropriate. It shows satn vp for flat sfcs.
Satn vp is different for a curved sfc like a droplet.

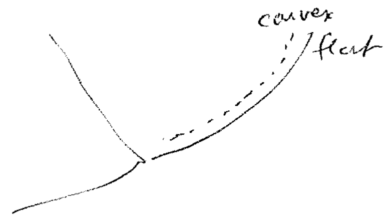
e_s (convex) > e_s (flat) > e_s (concave)



why: H-bonds have to be broken to take water mol from liquid to vapor (or for ice → vapor)

(model) Flat sfc have to break more bonds, so harder to evap, so vp lower.

Easy to evap from corner



So to form a droplet from pure vapor, need RH > 100% because forming a convex sfc.
(RH is defined relative to satn over flat sfc of pure water)

But in the atm there's smth that facilitates condensn: particles in the atm, that are soluble in water: "atmos. aerosol"
There are so many of these particles that essentially all water droplets in all clouds, worldwide, form by condensn of wv onto small ~~aerosol~~ particles that contain some soluble material:
"cloud condensn nuclei" (CCN).

what are these particles made of:

- sea salt
- soluble organic molecules from vegn
- sulfate, resultg from oxidn of sulfur gases emitted by
  - volcanoes
  - algae
  - [fossil-fuel] burng. of coal & oil

<u>Nucleation on aerosol particles is favored because</u>

(1) no need to form small convex sfc because partl already forme

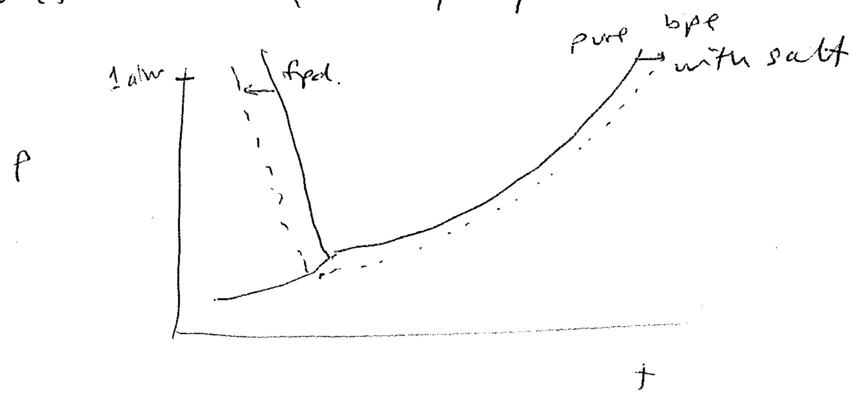
(2) e_s over soln < e_s over pure water

$$\uparrow\downarrow \qquad\qquad \uparrow\downarrow$$

H_2O Na^+ H_2O Cl^- $\qquad$ H_2O H_2O H_2O H_2O

salt dissolves in liq water but not in ice or vapor.

So if salt is present, liquid is favored.

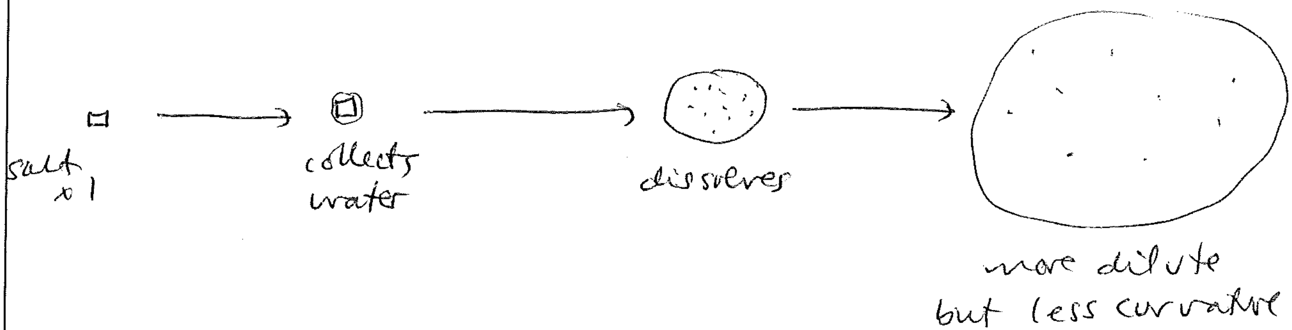


liquid range expanded by salt.

Result: what would be only small supsatn over pure water can be large supsatn over salt soln.

So salt can attract water even at RH < 100%

(salt in your saltshaker absorbs water from atm on humid summer day)



As droplet grows:

decrease curvature ⟹ ↓ e_s

dilution of salt ⟹ ↑ e_s

If <u>enough</u> salt (i.e. if nucleus is large enough), then droplet can grow until curvature effect on v.p. is very small, and droplet can continue to grow as essentially pure water (salt is diluted)

Typical RH in clouds 100.1 – 100.5 %

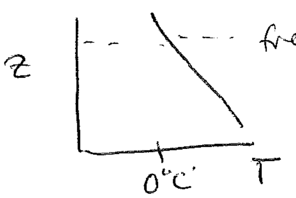
If few nuclei then RH gets higher before condensn occurs

aerosol numbers:

remote ocean	~ 100 per cm3
rural land	~ 1000
urban	~ 10,000

Ice xls in clouds

As you go up in the atm T ↓ ~6 deg /km



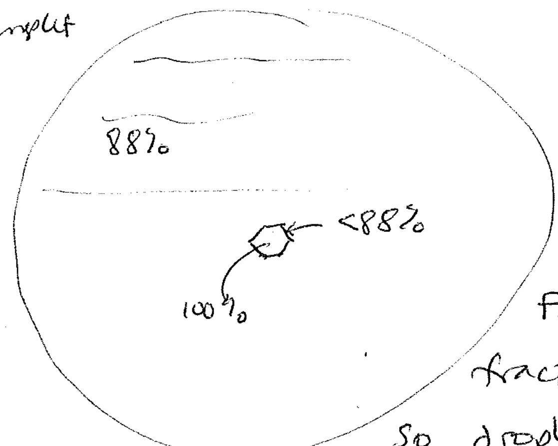
so it is common to have below-freezg temps in clouds. Even in tropics.

Ice can occur in a cloud that extends above the 0°C level. High clouds (cirrus) consist entirely of ice xls.

Freezing of water droplets

① As a droplet of pure water cools, it will freeze. But not at 0°C. Have to cool below zero, maybe not much below, maybe a lot.

② droplet



lots of H-bonds in liq. ~88% (! Hs are on an H bond bet 2 Os)
100% (all) formed within ice.
But molecules at ice/water interface make fewer H-bonds than either mols in liq or mols in ice.
For small xl, interface is a large fraction of total ice mols.
So droplet prefers to stay liquid unless ∃ already a surface to attach to by H-bondg

③ A bucket of water freezes at v. close to 0°C because wall of bucket serves as nucleus. It has many nucn sites, and you need only one

④ Once an ice embryo ~~freeze~~ forms in a droplet then the whole droplet freezes

⑤ If water is pure it will freeze at −37°C.

~~An "ice-forming nucleus" (not ccn) can allow freezing at higher temps.~~

Freezg can occur above −37°C if a solid impurity is present: "ice-forming nucleus" (IN)

A particle is effective as IN if

1. insoluble in water
2. capable of H-bondg
3. lattice spacg ~ ice
4. xlog sym hex

<u>nucln material</u>	<u>threshold temp for ice nucn</u>
ice	0°C
Ag I (artificial)	−4°C
clay minerals ~~(soil)~~ (dust)	~ −10°C
vegetation dust (dried & crumbled leaves) }	~~[illegible]~~ ≤ −4°C
bacteria }	≤

Feldspar is best

Fallg snow xls colld on ice sheets:

Clay minerals found at center of most xls.

(vugraf) handout

May come back if time to discuss non-clay.

---

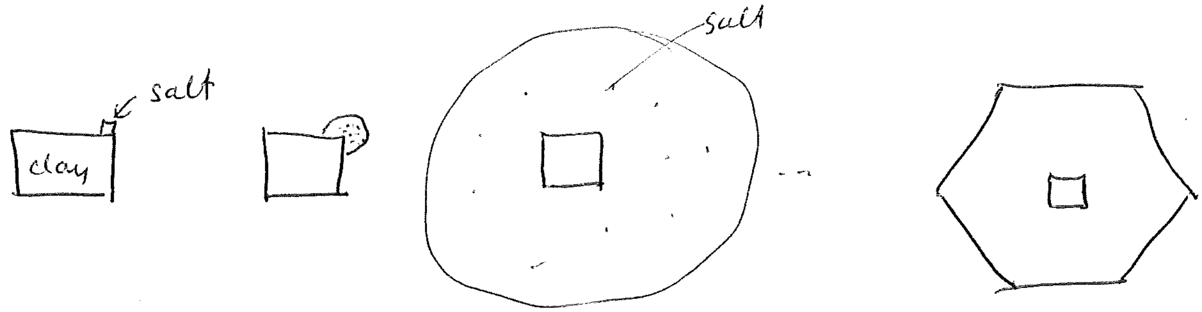
contrast two subsets of "atmos aerosol"

<u>cloud-condensn nuclei (CCN)</u>	&	<u>ice-formg nuclei (IN)</u>
small $r < 0.1\ \mu m$		large $r \sim 1\ \mu m$
soluble (salt)		insoluble (dust)
common ~ 1000 / cm³ (in this room if you're not sneezing)		rare
i.e. ~~≈~~ 10^6 / liter		~10 / liter.

---

so only a small fraction of cloud droplets will contain IN (all contain CCN)

So ice xl forms thus:

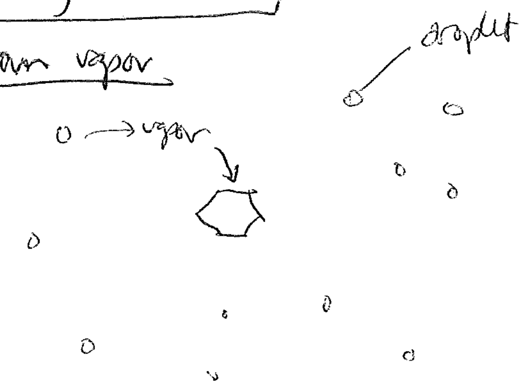


[or wv deposits directly ~~onto~~ as ice onto IN
□ ← wv cirrus clouds, Artk winter]

~~Growth of~~ snow

Growth of snow x1s

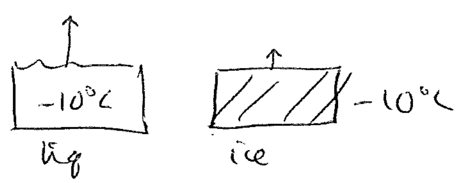
(1) <u>from vapor</u>



in "mixed cloud"

because of v.p. diff. (vusvar)

"Bergeron" process pronounced wrongly An cd-phys.
Marshall names it but doesn't give the correct explan
Marshall says its bec of diff in curvature.



Easier for mols to leave liq than ice.

In mixed cloud air is ~~nearly~~ intermed bet satd wrt liquid & satd wrt ice

~~because most droplets don't contain IN~~ ⟸ Doch

∴ supsatd wrt ice.

when say "RH is ..." If T<0°C must say RH over ice or RH over water. They're different.

② Riming (colln of supercooled droplets)

Most snow in marine climate (wa wash) is rimed.

1. snow xl forms by freezg of water droplet
2. grows by vapor depn until large enuf to fall
3. falls thru cloud & collects droplets as "rime"

so if you collect fallg snow xls & look under microscope, they will be rimed.

little bumps ~ 10 μm diam. (vugraf)

Heavily rimed → graupel (vugraf) → Hail.

To get unrimed go to polar ice sheet.

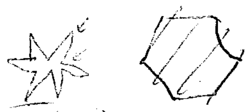
Ice xl shapes ("habits")

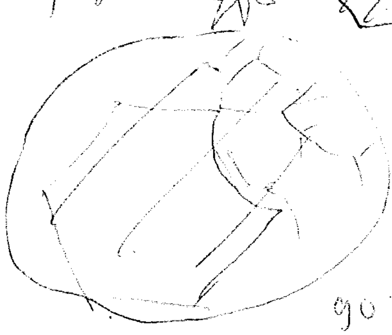
Basic shapes are all hex'l (slide)

classifn of forms (slide) dep on T, humidity

Humidity dets whether intricate or simple shapes

why? gets





molecules of wv carrying in, attaching.

will it fill in or grow branches?

if low hum, pass the outside corners?

go to cozy inside corners

In fact, can lose mass from outside corners.

if hum near satn.

In mixed cloud will be close to water-satn.

~~If~~ If v. small supsatn (wrt ice) then 'nearly equilibrium': growing slowly
short columns. Both axes grow at same rate results in small S/V,
what geom solid figure has smallest S/V : sphere
This is as close to a sphere as you can get while still maintaining
a hex'l shape.

By contrast, fast growth (large supsatn) leads to large S/V.

e (air in cloud)

← add to convex corners — large supsn.

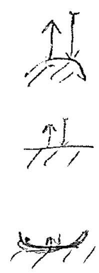
—— e_s ~~c~~ convex

← grow equidim. }

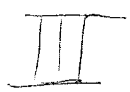
—— e_s flat — } near equilibrium

← fill in concavities }

—— e_s concave



So more intricate structure ~~as~~ ↑ supsatn.

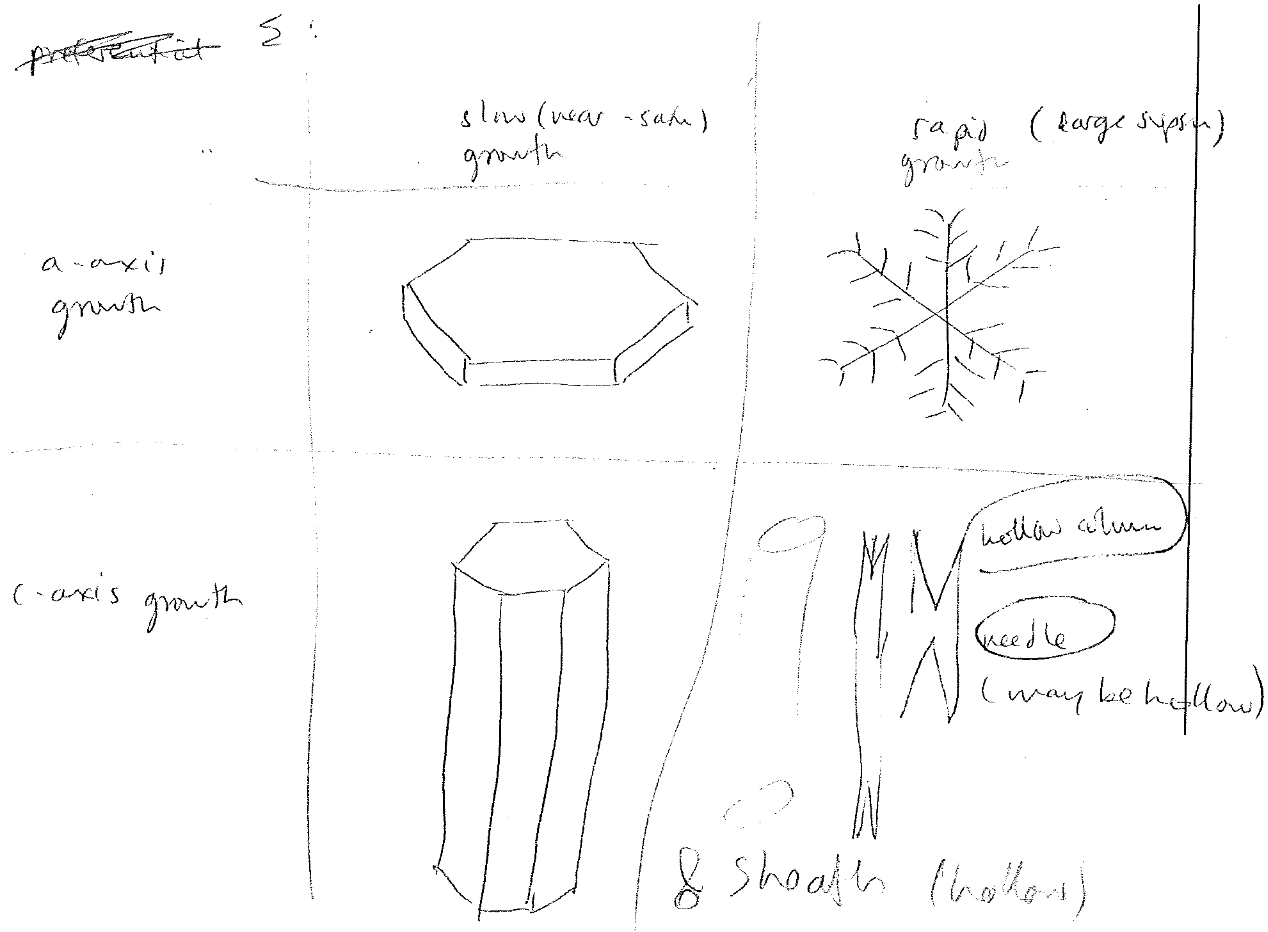
get  if condns Δ as fall. (vugraf)

show again vugraf ~~prism~~ plate – column – plate – column

(Temp)

preferential growth of a-dirn leads to plates,
c-dirn leads to columns. But both at low temp:

(pic SPO)



vugrafs of
hollow column,
needle.

Ice accum directly to sfc : 3 kinds : frost, rime, glaze

Frost ("hoar") vapor → solid (vugrafs) delicate, poor bonding

sfc rime (white) liq → solid (vugrafs)

supercooled cloud droplet T<0°C freezes on impact

glaze (freezg rain) liq → solid

clear

raindrop (T = 0°C) falls on cold sfc (T<0°C) then freezes.

what would an "ice storm" be?

what would be "icing" on an airplane wing?

---

homework

riming exercise (relevant to structure of hailstones)

A snow crystal of mass 1 mg at temp $T = -10°C$ collects rime at $-10°C$.
Freezing of rime releases LH. How much rime ~~(as percent of m)~~ will raise the temp of the snow xl to 0°C ?

warming		LH release
$10^{-3}\,g \cdot \frac{2.1\,J}{g\,deg} \times 10\,deg$	$=$	$m\,\frac{334\,J}{g}$

$m = 0.063$ mg i.e. 6 % of mass of xl

But warm xl loses heat ~~to cold air~~ by conduction to cold air
If riming is rapid, xl warms to mp so liq from rime-droplets flows

Hailstone structure