

ENV 407 – Atmospheric Processes: From Clouds to Global Scales
Phase Nucleation

1. Nucleation of a pure phase of one component is referred to as

- a) homogeneous
- b) heterogeneous

2. Most of the nucleation processes in the atmosphere is:

- a) homogeneous nucleation
- b) heterogeneous nucleation

Surface tension work

3. Write an expression for surface tension work

$$dW = \sigma dA$$

4. What are the units for surface tension?

energy / surface $(J m^{-2})$ or (Nm^{-1})

5a. The effect of surface tension on the internal energy of a droplet is (greater than, less than, the same) for a smaller drop.

As drop becomes larger \rightarrow surface tension effect on $u(\text{avg})$ is smaller.

6a. How much work is required to break a 1 cm cube of water into drops with radius 10 μm ?

(use surface tension 0.076 N m^{-1}) $\rightarrow \Delta W = \sigma \Delta A$ ← difference in droplet area before and after splitting.

Surface area of 10 μm drop: $4\pi r^2 = 4\pi (10 \times 10^{-6})^2 = 1.256 \times 10^3 \times 10^{-12} = 1.256 \times 10^{-9} \text{ m}^2$

Surface area of cube 1 cm: $6 \times 1 \text{ cm}^2 = 6 \times (10^{-2})^2 = 6 \times 10^{-4} \text{ m}^2$

Volume of 10 μm drop = $\frac{4}{3} \pi r^3 = \frac{4}{3} \pi (10 \times 10^{-6})^3 = 4.18 \times 10^3 \times 10^{-18} = 4.18 \times 10^{-15} \text{ m}^3$

of drops: $\frac{10^{-6} \text{ m}^3}{4.18 \times 10^{-15}} = 2.392 \times 10^8$

$dW = \sigma \kappa dA \sim \Delta W = \sigma \Delta A = 0.076 \times (2.392 \times 10^8 \times 1.256 \times 10^{-9} - 6 \times 10^{-4}) = 2.26 \times 10^2 \text{ J}$

16. Refer to Fig. 5.3, which is a graph of Kelvin's equation

$$r^* = \frac{2\sigma_w}{\rho_l R_v T \ln S} \quad (5.14a) \quad \text{see } \textcircled{*}$$

a) Has a drop with radius $1 \times 10^{-3} \mu\text{m}$ and $S=1.5$ been activated (i.e. will it grow spontaneously)?

$$r^* = \frac{1.10 \times 10^{-9}}{0.4} = 2.75 \times 10^{-9} \text{ m} = 2.75 \times 10^{-3} \mu\text{m} \quad r < r^* \Rightarrow \text{no growth}$$

b) Has a drop with radius $1 \times 10^{-3} \mu\text{m}$ and $S=4$ been activated (i.e. will it grow spontaneously)?

$$r^* = \frac{1.10 \times 10^{-9}}{1.38} = 0.8 \times 10^{-9} \text{ m} = 0.8 \times 10^{-3} \mu\text{m} \quad r > r^* \Rightarrow \text{spontaneous growth}$$

17. The formation of pure water droplets requires a vapor pressure that is (less than, equal to, greater than) the saturation vapor pressure over a plane surface of pure water

18. If the relative humidity of the air is 100%, droplets of pure water will
a) evaporate b) grow further by condensation c) remain the same size

19. Are values of $S=1.5$ and $S=4$ observed in the atmosphere? What is a realistic maximum value of S that is observed in the atmosphere? *No. realistic $S = 1.001 - 1.01$*

20. Aerosol particles that attract water are called

- a) hydrophobic
b) hydrophilic

21. Cloud condensation nuclei (CCN) are aerosol particles that nucleate water drops at supersaturations less than

- a) 100%
 b) 10%
c) 1%

22. Which of these aerosol particles are likely to act as cloud condensation nuclei (circle all that apply)

- a) clay b) NaCl c) (NH₄)₂SO₄ d) AgI e) pollen f) sand *can meet: clay may but not according to Köhler theory*

23. The saturation vapor pressure over a solution is (less than, equal to, greater than) the vapor pressure over pure water.

24. The saturation vapor pressure over an electrolytic solution is (less than, equal to, greater than) the saturation vapor pressure over a non-electrolytic solution.

*electrolytes dissociate so the # of molecules of effective molecules goes up
 non-electrolytes do not dissociate.*

$\textcircled{*}$

$$\frac{2 \times 0.076}{10^3 \frac{8.314}{18 \times 10^{-3}} 298 \ln S} = \frac{1.70 \times 10^{-9}}{\ln S}$$

$T = 298 \text{ K}$

$\ln 1.5 = 0.4$
 $\ln 4 = 1.38$

Combination of Kelvin's Law (#16, pure droplets with surface tension effects) with Raoult's Law (4.48) for solutions yields Kohler's equation:

$$\frac{e_s(r, m_{sol})}{e_s} = \left[1 - \frac{b}{r^3} \right] \exp(a/r) \quad (5.17)$$

where $a = 2\sigma_w / (\rho_l R_v T)$. Use the Kohler curve below to estimate:

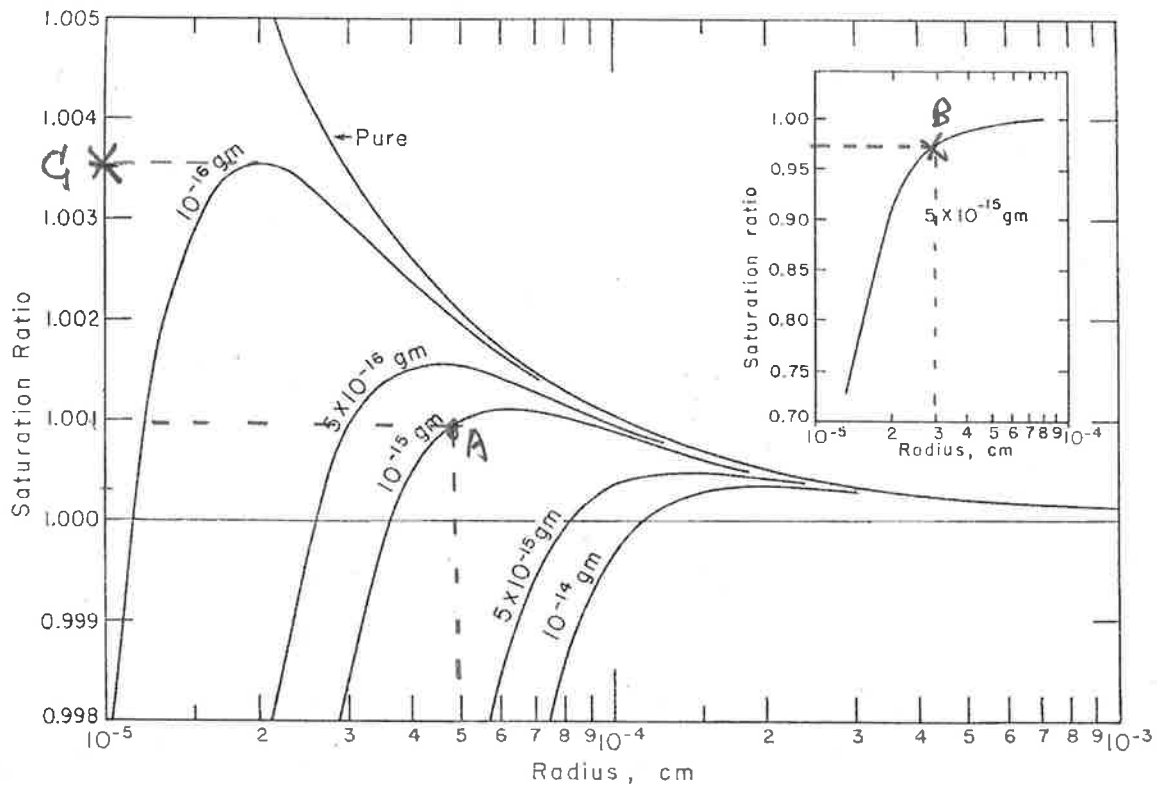


FIG. 2.4.—Curves of equilibrium saturation ratio of water droplets containing the stated mass of sodium chloride compared with Kelvin curve for pure water droplets. Inset: curve for 5×10^{-15} g NaCl on a compressed scale extended to the droplet size at which the given amount of NaCl would form a saturated salt solution in the droplet. All computations are made for a temperature of 25°C , but the values are very nearly the same at other atmospheric temperatures.

25. The radius of the droplet that will be in equilibrium on a NaCl particle of mass 10^{-15} g in air which is 0.1% supersaturated.

$\rightarrow S = 1.001 \Rightarrow \text{point A} \Rightarrow 5 \times 10^{-5}$ cm radius.

26. The relative humidity of the air adjacent to a droplet of 0.3 microns with 10^{-15} g NaCl.

$0.3 \times 10^{-6} \text{ m} = 0.3 \times 10^{-4} \text{ cm} = 3 \times 10^{-5} \text{ cm} \Rightarrow \text{point B}, S = 0.975 \Rightarrow 97.5\% \text{ RH}$

27. The critical supersaturation required for a NaCl particle of mass 10^{-16} g to grow beyond the haze state.

point C $\Rightarrow S = 1.0035 \Rightarrow S = 0.35\%$ supersaturation.

28. Consider the droplet with radius r with a CCN consisting of 10^{-15} g NaCl in an environment with saturation ratio S , as indicated by point A. Is the droplet growing, evaporating, or in equilibrium?

In equilibrium (left of the critical radius).

29. Consider the droplet with radius r with a CCN consisting of 10^{-15} g NaCl in an environment with saturation ratio S , as indicated by point B. Is the droplet growing, evaporating, or in equilibrium?

In equilibrium (RH < 100%, droplet size left of the critical point)