

## Atmospheric Processes

Ex session – Tue 7 Oct 2025

### Ex.1

The sizes and concentrations of CCN, cloud droplets and raindrops differ. Which of the following is/are true?

- (a) The CCN size is always smaller than 1  $\mu\text{m}$ .
- (b) The concentration and volume of raindrops are in general a factor of one million larger than those of cloud droplets.
- (c) Higher supersaturation implies a larger cloud droplet concentration and thus increased droplet size.

### Ex.2

Cloud droplets grow initially by diffusional growth. Which of the following is/are true?

- (a) The droplet growth equation takes the diffusion of water vapor and heat into account.
- (b) In warm-phase clouds, growth by diffusion is stronger at higher temperatures.
- (c) The supersaturation decreases with stronger updraft.

### Ex.3

Break-up limits the observed raindrop sizes in the atmosphere.

- (a) Name three ways in which the break-up of a raindrop can occur.
- (b) Briefly describe the difference among those.

### Ex.4

A drop with an initial radius of 100  $\mu\text{m}$  falls through a cloud containing 100 droplets per cubic centimeter that it collects in a continuous manner with a collection efficiency of 0.8. If all the cloud droplets have a radius of 10  $\mu\text{m}$ , how long will it take for the drop to reach a radius of 1 mm? You may assume that the fall speed  $v$  (in m/s) of a drop of radius  $r$  (in meters) is given by  $v=6 \cdot 10^3 r$ . Assume that the cloud droplets are stationary and that the updraft velocity is negligible.

### Ex.5

A cloud is cylindrical in shape with a cross-sectional area of 10  $\text{km}^2$  and a height of 3 km. All of the cloud is initially supercooled and the liquid water content is 2  $\text{gm}^{-3}$ .

- (a) If all of the water in the cloud is transferred onto ice nuclei present in a uniform concentration of 1/liter, determine the total number of ice crystals in the cloud and the mass of each ice crystal produced.
- (b) If all the ice crystals precipitate and melt before they reach the ground, what will be the total rainfall produced?

**Ex.6**

Cloud seeding with water droplets.

- (a) If 40 liters of water in the form of drops of 0.5 mm diameter was poured into the top of a cumulus cloud and all of the drops grew to a diameter of 5 mm before they emerged from the base of the cloud, which has an area of 10 km<sup>2</sup>, what would be the amount of rainfall induced?
- (b) What is the increase in the mass of the droplets?
- (c) Compare the increase in the mass with that of a droplet of 20 μm radius that is introduced at the cloud base, travels upward, then downward, and finally emerges from the cloud base with a diameter of 5 mm.

**Ex.7**

Once an ice crystal has formed, it generally grows until it reaches precipitation size. Which of the following is/are true?

- (a) The diffusional mass growth of an ice crystal does not depend on its shape.
- (b) All water vapor molecules colliding with an ice crystal are incorporated into the ice crystal surface since the sticking coefficient is close to unity.
- (c) High supersaturations with respect to ice lead to the formation of needles and plates.

**Ex.8**

Consider a cloud which consists of ice crystals at the cloud top and supercooled droplets further below. The ice crystals can collide with these droplets when falling as (solid) precipitation. Which of the following is/are true?

- (a) Riming is an accretion process.
- (b) During riming, additional ice crystals can be produced; thus riming can increase the ice crystal concentration of a cloud significantly.
- (c) In an environment of high supercooling, large INP concentration, and low updraft velocities, very large precipitation particles can be formed due to riming.
- (d) For riming, the sticking efficiency is close to one due to the quasi-liquid layer.

**Ex.9**

Consider a mixed-phase cloud containing ice crystals as well as liquid droplets, in conditions leading to supersaturations with respect to ice of 5% and with respect to water of 1%. We focus on an ice crystal and a droplet both growing by vapor deposition (diffusion).

(a) Which of the two cloud particles grows faster? Explain the main reason for the difference in growth speed.

(b) How would the situation in the mixed-phase cloud change for supersaturation with respect to ice but subsaturation with respect to water? Explain qualitatively in a few sentences.