Chapter 5
FORMS OF CONDENSATION AND PRECIPITATION

Answers to the Chapter Review

1. Clouds are classified on the basis of their appearance (form) and height. On the basis of appearance, three forms are recognized: cirrus, stratus, and cumulus. Height categories include low (below 2000 meters), middle (2000–6000 meters), high (above 6000 meters), and clouds of vertical development.

2. High clouds are always thin because of the low temperatures and thus the small quantity of water vapor available at the altitudes where they form.


4. Layered clouds generally indicate that the air is stable, whereas clouds of vertical development are associated with instability.

5. Condensation nuclei serve as surfaces on which water vapor condenses. If absent, a relative humidity well in excess of 100% is necessary to produce clouds.

6. The essential difference is the method and place of formation. Clouds form above the surface and result from the adiabatic cooling of rising air. Fogs form at the surface and, with one exception, are not produced by adiabatic cooling.

7. Radiation fog, advection fog, and upslope fog result when air near the ground is cooled below its dew point. Steam fog and frontal fog form when evaporation brings about saturation.

- **Radiation fog**: On a clear night, the ground cools rapidly. The air in contact with the chilled ground is cooled below the dew point, resulting in a relatively thin layer of fog. Slight turbulence or cold air drainage into low places may result in a thicker accumulation of this fog.

- **Advection fog**: When warm, moist air moves over a cold surface, it is chilled below the dew point. Turbulence associated with the accompanying 10–30 km/h winds facilitates cooling through a thick layer of air and also carries the fog to considerable heights.

- **Upslope fog**: A fog that forms when relatively humid air moves upslope and cools adiabatically below the dew point.

- **Steam fog**: An evaporation fog formed when cool air moves over warm water. Evaporation from the water saturates the air above. As the rising water vapor meets the cooler air, it immediately condenses, giving the appearance of steam rising from the water surface.

- **Frontal (precipitation) fog**: Evaporation of rain in cool humid air brings about saturation and fog.

8. When radiation fog is said to “lift,” the fog actually does not rise. The Sun warms the ground, which, in turn, heats the air near the surface first. Thus, the fog evaporates from the bottom up, giving the impression of lifting.

10. Warm, moist air from the Pacific Ocean moves over the cold current that parallels the West Coast, producing advection fog.

11. The Bergeron process relies on the fact that cloud droplets do not freeze until they reach a temperature below the freezing point, and even then only in the presence of freezing nuclei (solid particles that have a crystal form similar to that of ice). Because freezing nuclei are much less abundant than condensation nuclei, many clouds exist in the liquid state while at temperatures well below 0°C. These are supercooled clouds. The freezing nuclei present promote the formation of a few scattered ice crystals. Since ice crystals are more efficient absorbers of water vapor, they consume the “excess” water vapor, which lowers the relative humidity near the surrounding liquid cloud droplets. In turn, the water droplets evaporate in order to replenish the diminishing water vapor, thereby providing a continuous source of vapor for the growth of ice crystals, which eventually grow large enough to fall.

12. Whereas the Bergeron process operates in supercooled clouds, the collision–coalescence process produces precipitation in warm clouds (above 0 °C). In the collision–coalescence process, large cloud droplets fall more rapidly than smaller droplets, sweep up the smaller ones in their path, and grow. Experiments show that atmospheric electricity may play an important role in this process.

13. The Bergeron process. The other precipitation–production process (collision–coalescence) is associated only with warm clouds where temperatures are above 0°C.

14. Sleet (frozen raindrops) forms when raindrops leave an above-freezing layer of air and descend through a subfreezing layer. The raindrops freeze and reach the ground as small ice pellets. Glaze forms under circumstances similar to sleet except that the subfreezing layer near the ground is not thick enough to allow the raindrops to freeze. Rather, the raindrops become supercooled as they traverse the subfreezing air and turn to ice upon striking objects or the ground. The result may be a thick coating of ice on these objects.

15. Hail is produced only in cumulonimbus clouds where updrafts are strong and where there is an abundant supply of supercooled water. Hailstones begin as small embryonic ice pellets that grow by collecting supercooled cloud droplets as they fall through the cloud. If a strong updraft is encountered, the hail may be carried upward again and begin the descent anew. Hail may also form from a single descent through an updraft. In this case, the characteristic layered structure of the hailstone is attributed to variations in the rate at which supercooled droplets accumulate and freeze, which, in turn, is related to the quantity of supercooled water in different parts of the cloud. The ultimate size of hailstones depends upon the following: 1) the strength of updrafts, 2) the concentration of supercooled water, and 3) the length of the path through the cloud.

16. The standard rain gauge magnifies the actual rainfall depth 10 times. This allows for accurate measurement to the nearest 0.025 cm or 0.01 in.

17. In the tipping-bucket gauge, when one compartment fills, it tips and empties its water. Meanwhile, the other compartment takes its place. Each time a compartment tips, an electrical circuit is closed and the amount of precipitation is recorded on a graph. In the case of a weighing gauge, precipitation is caught in a cylinder that rests on a spring balance. As the cylinder fills, the movement is transmitted to a pen that records the data. From recording gauges we can determine the intensity of precipitation as well as the total amount.

18. Errors arise when gauges are shielded from obliquely falling precipitation by buildings, trees, and so on. Wind and accompanying turbulence make accurate collection difficult because some of the precipitation will blow across the gauge and not fall into it.
19. Silver iodide crystals are effective freezing nuclei because their crystalline structure is similar to that of ice.

20. If cloud seeding is to have a chance of success, clouds must be present and at least a portion of the cloud must be supercooled.

21. The term frost is used when air temperatures fall to 0 °C or below. White frost, on the other hand, refers to the deposits of ice crystals that sometimes accompany freezing or subfreezing temperatures.

22. Smudge fires produce particles that reduce radiation loss. As sprinklers distribute water to plants, they add heat from the warmth of the water itself and from the latent heat of fusion that is released when the water freezes. Wind machines mix warmer air aloft with cooler surface air.

23. Several factors contribute to greater precipitation in and downwind of cities. Among these are the following:
   a) Industries and transportation systems discharge large quantities of hygroscopic particles and freezing nuclei into the atmosphere.
   b) The urban heat island effect produces warm parcels of air that rise because of their buoyancy. Surface heating also steepens the environmental lapse rate, which enhances atmospheric instability.
   c) The surface roughness of cities slow lower-level airflow that results in convergence, enhancing the upward flow of air. Surface roughness also impedes the progress of weather systems that may cause rain-producing clouds to linger over cities.

Answers to the Chapter Problems

1. No fog will occur because the temperature at 6:00 A.M. is above the dew point.

2. Yes; at 4:00 A.M.; radiation fog.

3. 5 mm: 327 s = 5 min, 27 s ; 2 mm: 470 s = 7 min, 50 s; 0.5 mm: 1543 s = 25 min, 43 s.

4. 25 h; the cloud droplet is so small that the motion of the air would keep it suspended.

5. 0.52 cubic millimeters.

6. One million times greater.

7. 0.79 square millimeters.

8. 25 times greater.