Factors Affecting Evaporation Rates of Water

The net evaporation rate of water at a location is determined by

- amount of energy available: the more energy available, and thus the higher the temperature, the faster the evaporation of available water
- surface area of the water: the more spread out the water, the greater the air-water interface and the faster the evaporation
- degree of saturation of the air with water vapor: the higher the water vapor content of the air, the closer the air is to being saturated with water vapor and the slower the net evaporation rate
- wind speed: wind often moves air at the water-air interface that is high in water vapor and replaces it with air that is less saturated and thus speeds up evaporation rates. The greater the speed of the wind, the more air replacement occurs.

Humidity, Temperature, and Dew Point

Like moisture, **humidity** is a general term that refers to the water vapor content of the atmosphere. The amount (mass) of water vapor in each unit volume of air is called the absolute humidity. Absolute humidity is often measured in grams of water vapor per cubic meter of air. The maximum absolute humidity, or moisture capacity, increases rapidly with an increase in air temperature, as shown in the graph in Figure 7-12. This means that the total amount of water vapor the air can hold—its capacity—increases with an increase in temperature, or in other words, hotter air can hold more water vapor than colder air.

The ratio of the amount of water vapor in the air (absolute humidity) to the maximum amount it can hold (its moisture capacity) is **relative humidity.** It is usually expressed as a percent. In simpler terms, relative humidity is the amount of water vapor in the air compared to the amount of water vapor the air can hold at a specific temperature. The closer the absolute humidity is to the maximum absolute humidity (capacity) the higher the relative humidity. Note that relative humidity is a percentage of saturation, or capacity, NOT how much water vapor there is in a volume of air.

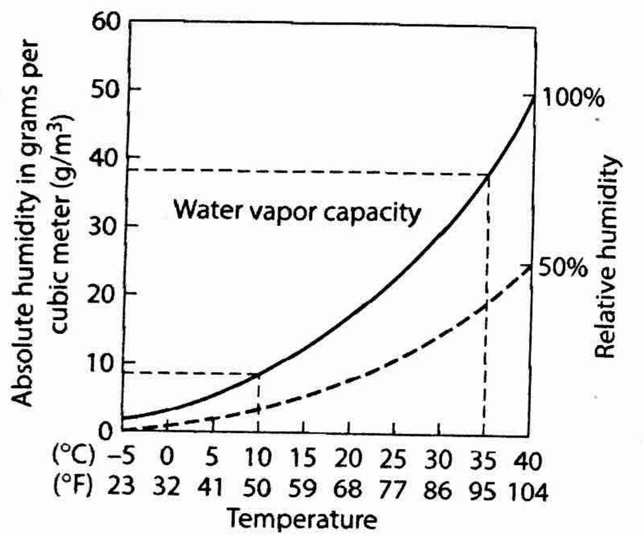


Figure 7-12. Relationship between air's capacity for water vapor and temperature: Note that air with a temperature of 35°C can hold about four times more water vapor than air at 10°C can. Note that when the air at 10°C has 50 percent relative humidity, it has only about 1/4 as much water vapor as air at 35°C with 50 percent relative humidity.

Relative Humidity and Temperature At any given time and place, the air has a certain amount of water vapor (humidity), with a corresponding absolute humidity. If the temperature of the air changes but the amount of water vapor remains the same, the relative humidity will change. For example, if the temperature increases, the relative humidity will decrease. This occurs because the capacity increases with the increase in temperature, while the absolute humidity remains the same. On the other hand, if the temperature decreases while the absolute humidity remains the same, the relative humidity will increase.

If the temperature of the air remains constant, but more water vapor is added to the air by evaporation or transpiration, both the absolute humidity and the relative humidity will increase. The relative humidity increases because the air becomes closer to its capacity, or saturation point, when more water vapor is added.

Dew Point If the temperature of the air decreases while the absolute humidity remains the same, the temperature will eventually reach a point at which the absolute humidity equals capacity. At this temperature, the relative humidity will be 100 percent. This temperature is called the **dew point**—the temperature at which air is filled with water vapor. If the air temperature drops below the dew point, water vapor in the air will condense to liquid water or sublimate to a solid.

The dew point depends on the absolute humidity and not on the relative humidity. As the amount of water vapor in the air increases, the dew point also rises because the more water vapor in the air, the closer the air is to its saturation point—the dew point.

Measuring Relative Humidity It is difficult to directly measure absolute humidity or determine the air's capacity to hold water vapor. Relative humidity is therefore measured by indirect methods. Two similar instruments are commonly used to help measure relative humidity—a sling **psychrometer** and a hygrometer. Figure 7-13 shows these two instruments. Both use two thermometers. The instruments contain an ordinary thermometer called a dry-bulb thermometer, and another thermometer with a wick around its bulb, called the wet-bulb thermometer. With a sling psychrometer, when the wick is moistened and the thermometers are whirled in the air, the temperature of the wet bulb drops because of the cooling effect of the evaporation of the water. The amount of cooling depends on the rate of evaporation, and is therefore related to the relative humidity.

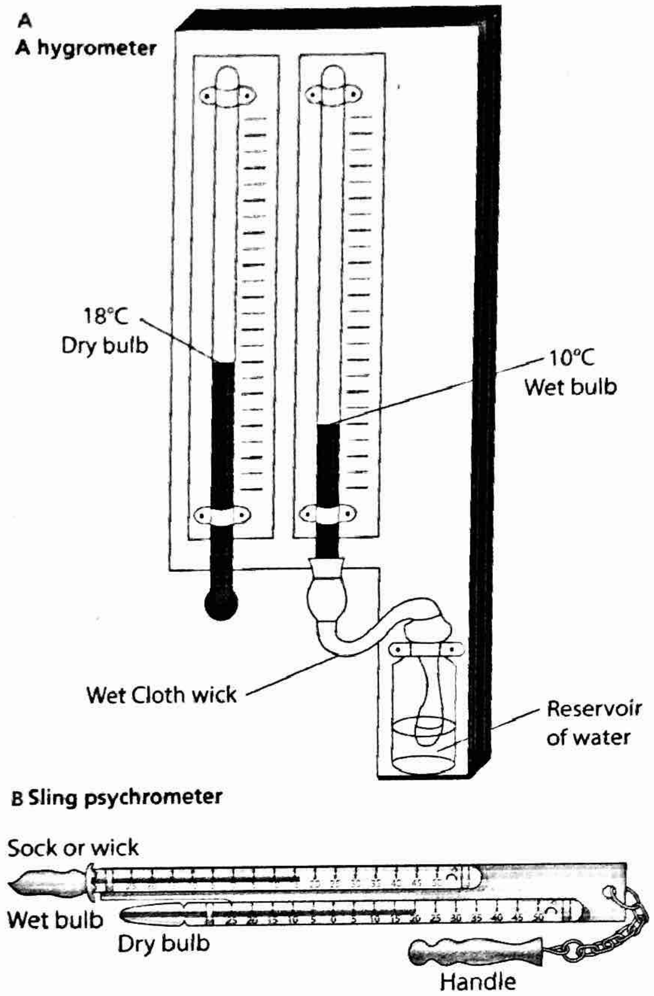


Figure 7-13. Hygrometer and Sling Psychrometer: Both the hygrometer (A) and sling psychrometer (B) use the difference in the dry and wet-bulb temperature readings to help determine relative humidity and dew point. Note that the dry-bulb reading on the sling psychrometer at 20°C is the same as a regular temperature reading at 20°C.

To determine percent relative humidity, use the Relative Humidity (%) tables in the *Earth Science Reference Tables* and the following procedure. Ⓡ

- Locate the dry-bulb reading on the left-hand side of the Relative Humidity (%) chart in the *Earth Science Reference Tables.*
- Subtract the wet-bulb reading from the dry-bulb reading.
- Locate the difference between the wet-bulb and dry-bulb readings across the top of the chart.
- Follow the horizontal row for the dry-bulb reading to the right until it meets the vertical column running down from the top. This number is the relative humidity.

See Figure 7-14 for an example for determining relative humidity.

Determining Dew Point To determine the dew point, you need the dry-bulb and wet-bulb readings from a sling psychrometer or hygrometer and the

Dry-bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (°C)									
	1	2	3	4	5	6	7	8	9	10
−20	28					↓				
−18	40					↓				
−16	48	0				↓				
−14	55	11				↓				
−12	61	23				↓				
−10	66	33	0			↓				
−8	71	41	13			↓				
−6	73	48	20	0		↓				
−4	77	54	32	11		↓				
−2	79	58	37	20	1	↓				
0	81	63	45	28	11	↓				
2	83	67	51	36	20	↓ 6				
4 →	→ 85	→ 70	→ 56	→ 42	→ 27	→ 14	= 14% Relative humidity			
6	86	72	59	46	35	22	10	0		
8	87	74	62	51	39	28	17	6		
10	88	76	65	54	43	33	24	13	4	

Figure 7-14. Determining relative humidity: Suppose the dry-bulb reading is 4°C and the wet-bulb reading is −2°C. The difference is 6°C. Reading across from 4°C and down from 6°C, you find a relative humidity of 14%.

Dewpoint Temperatures chart in the *Earth Science Reference Tables*. Use the following procedure which is very similar to the procedure used to determine the relative humidity:

- Locate the dry-bulb reading on the left-hand side of the chart.
- Subtract the wet-bulb reading from the dry-bulb reading.
- Locate the difference between the wet-bulb and dry-bulb readings across the top of the chart.
- Follow the horizontal row for the dry-bulb reading to the right until it meets the vertical column running down from the difference between the wet-bulb and dry-bulb readings. This number is the dew point temperature.

For example, suppose the dry-bulb reading is 8°C, and the wet-bulb reading is 6°C. The difference is 2°C. Reading across from 8°C and down from 2°C, you find a dew point temperature of 3°C.

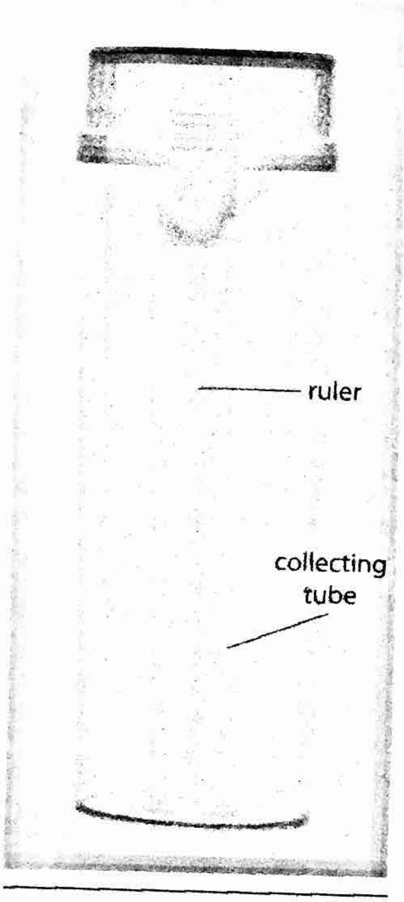


Figure 7-15. Rain/Precipitation gauge: This instrument collects the precipitation and allows it to be measured in units such as inches or centimeters using a ruler.

Cloud Formation

If the temperature of the air cools (often by expanding) below the dew point, the water vapor will usually condense to a liquid or sublimate to a solid (deposition), changing to microscopic liquid water droplets or ice crystals, respectively. At Earth's surface, condensation produces liquid dew, and sublimation produces the solid frost. If the temperature in the atmosphere is above 0°C, condensation produces water droplets, which appear as a cloud when grouped. Some clouds are composed of ice crystals, which form when water vapor sublimates to a solid. A cloud is therefore a collection of liquid water droplets and/or ice crystals suspended in the atmosphere and dense enough to be visible. If there is only a low density of water droplets or ice crystals, a condition called haze may result. **Cloud cover**—found on some weather maps—is the fraction or percent of the total sky at a location that is covered by clouds. If a cloud is on, or just above, Earth's surface, it is called fog. The condensation or sublimation that forms clouds and fog releases tremendous amounts of energy into the troposphere. This is the potential energy that was imparted to water molecules during evaporation and sublimation to a gas.

Besides needing saturated air, condensation usually requires a surface upon which the vapor can condense. This is called the condensation surface. In the formation of clouds and fog, the condensation surfaces are aerosols such as dust, bacteria, and volcanic ash. In the formation of dew, the condensation surfaces are the features of Earth's surface like grass and leaves.

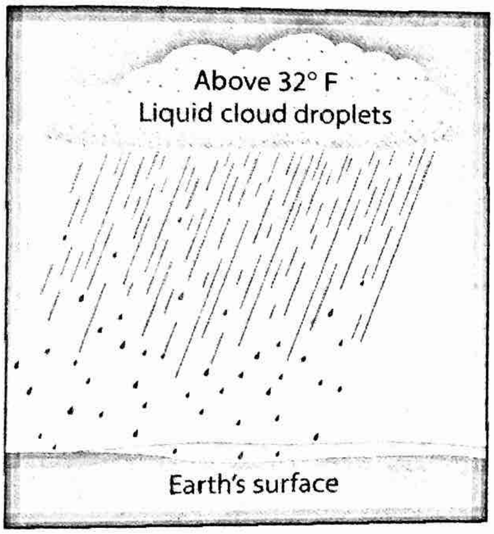
Since air temperature and dew point temperature both decrease with altitude in the troposphere, the altitude where temperature and dew point are the same is the level where clouds form by condensation or sublimation. This level is often seen as the flat bottoms on some clouds.

Precipitation

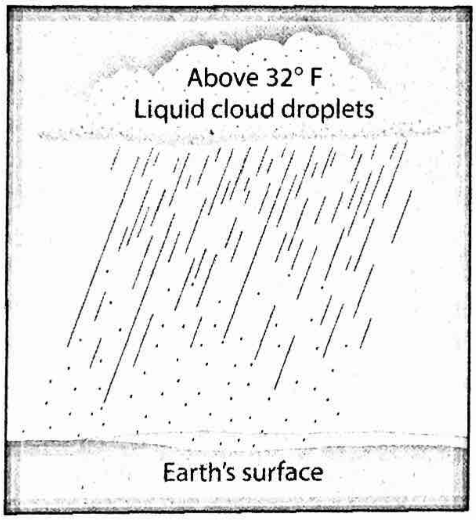
The falling of liquid or solid water from clouds toward the surface of Earth is **precipitation.** For precipitation to occur, the ice crystals or water droplets in clouds must come together to become big enough so that they will fall under the influence of gravity. The forms in which precipitation occur are rain, drizzle, snow, sleet, freezing rain, and hail. The conditions that result in the formations of these different types of precipitation are shown in Figure 7-16.

A rain gauge, a type of precipitation gauge, is used to measure liquid precipitation. (See Figure 7-15.) It is measured in depth—usually inches or centimeters. Snow depth is often measured with a ruler, or it is gently warmed and the depth of liquid is measured and reported as precipitation. A rain shower is brief, rapidly forming, rapidly ending, and often heavy rain associated with thunderstorm-type clouds. A snow shower is a brief, heavy snowfall.

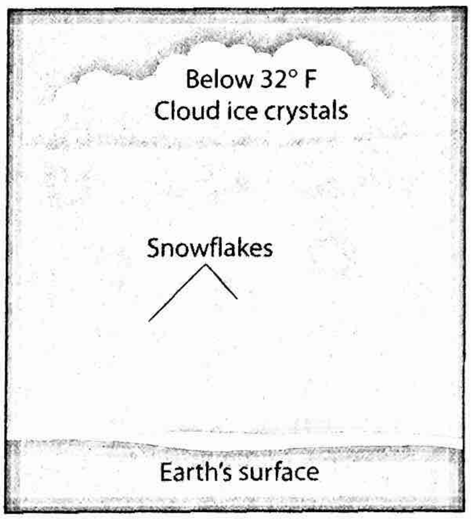
To review, precipitation usually occurs when rising air cools portions of the troposphere. This action reduces the differences between air temperature



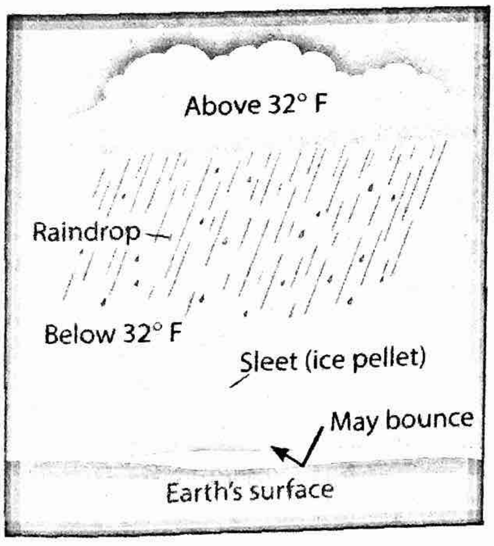
Rain Falling liquid droplets larger than 0.2 mm in diameter; may be melted snow



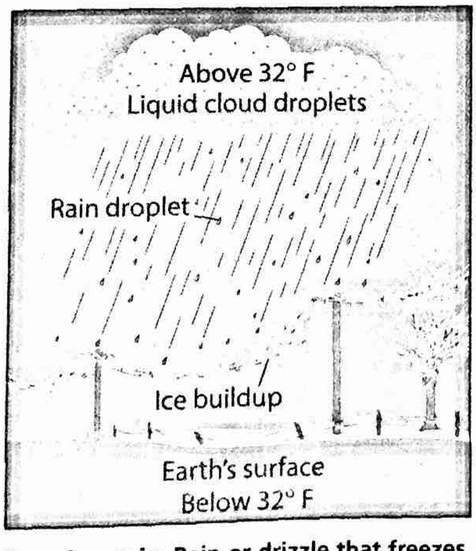
Drizzle Falling liquid droplets from 0.2 to 0.5 mm in diameter



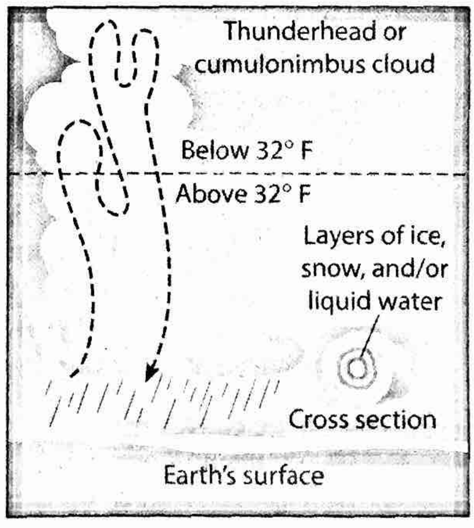
Snow Falling ice crystals formed by combining cloud ice crystals



Sleet Solid pellets of ice that form by freezing of rain drops as they fall



Freezing rain Rain or drizzle that freezes on contact with features of Earth's surface



Hail Layers of ice, snow, and water formed by many up-and-down movements in a thunderstorm cloud; may be grapefruit-sized

Figure 7-16. Forms of precipitation

and the dew point temperature until the water content of the air equals the air's capacity to hold water vapor. If the air continues to cool below the dew point, liquid water droplets (by condensation) or tiny ice crystals (by sublimation/deposition) form—usually producing clouds. When these liquid or solid water cloud particles collide or otherwise combine, they become heavy enough to fall, producing precipitation. The factors that cause the rising air, and thus cooling, are upward movement of air at fronts, air blowing against a mountain, or portions of air that are selectively heated at Earth's surface, such as over a dark road.

Atmospheric Transparency and Precipitation

The more pollutants added to the atmosphere by the activities of people and nature, the more aerosols are present. The more aerosols in the air, the less transparent the atmosphere is to insolation. How transparent the atmosphere is to insolation is called **atmospheric transparency.** When the atmosphere is less transparent, it means that more energy from the sun is absorbed or reflected by the atmosphere, resulting in less insolation reaching Earth's surface.

When the atmosphere has an aerosol content so high that distant images are blurred, and a cloudless sky does not appear blue, the condition is called haze. A haze or fog, usually brownish, which is highly polluted is smog. Condensation in cloud formation incorporates some of the aerosols, and these aerosols are removed from the atmosphere during precipitation. The falling liquid or solid water also collects other aerosols on the way down, thus lowering air pollution levels and cleaning the atmosphere. **Visibility**—sometimes found on weather maps—is how far you can see along Earth's surface expressed in miles. The poorer the atmospheric transparency, the lower the visibility.

Review Questions

36. As altitude within the troposphere increases, the amount of water vapor generally

(1) decreases, only
(2) increases, only
(3) remains the same
(4) decreases, then increases

37. By which process does moisture leave green plants?

(1) convection
(2) condensation
(3) transpiration
(4) radiation

38. Most moisture enters the atmosphere by the processes of

(1) convection and conduction
(2) condensation and radiation
(3) reflection and absorption
(4) transpiration and evaporation

39. The primary source of most of the moisture in Earth's atmosphere is

(1) soil-moisture storage
(2) rivers and lakes
(3) melting glaciers
(4) oceans

40. As the exposed area of a moist object decreases, the rate of evaporation of the liquid from that object

(1) decreases
(2) increases
(3) remains the same

41. As the amount of light energy striking a moist object increases, the rate of evaporation of the liquid from that object

(1) decreases
(2) increases
(3) remains the same

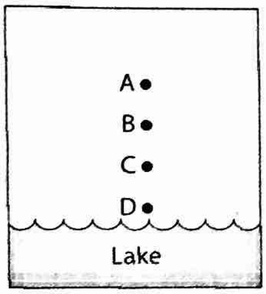
42. As the amount of water vapor in a given volume of air increases, the rate of evaporation from a moist object

(1) decreases
(2) increases
(3) remains the same

43. There will most likely be an increase in the rate at which water evaporates from a lake if there is

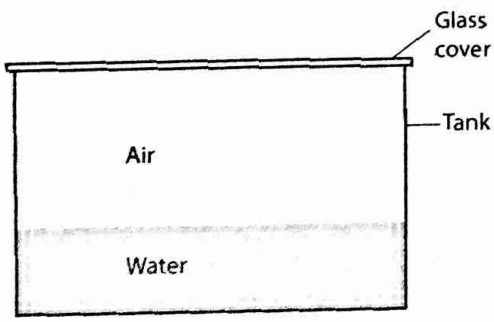
(1) a decrease in the temperature of the air
(2) a decrease in the altitude of the sun
(3) an increase in the moisture content of the air
(4) an increase in the wind velocity

44. In the following diagram, at which location would the amount of water vapor in the air most likely be greater?



(1) A
(2) B
(3) C
(4) D

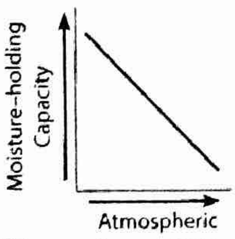
45. In the closed aquarium shown in the following diagram, the amount of water evaporating is equal to the amount of water vapor condensing.



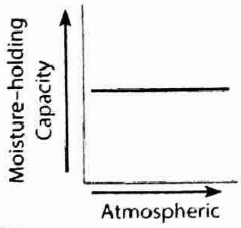
Which statement best explains why these amounts are equal?

(1) The glass sides of the aquarium are warmer than the water.
(2) The air in the aquarium is 50 percent saturated.
(3) The relative humidity outside the aquarium is 100 percent.
(4) The air in the aquarium is saturated.

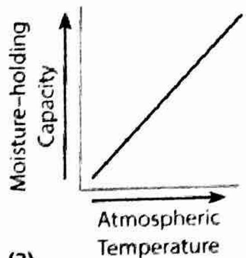
46. Which graph best represents the relationship between the moisture-holding capacity of the atmosphere and atmospheric temperature?



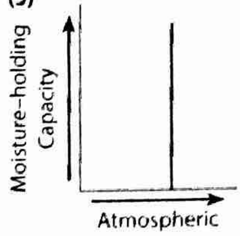
(1)



(2)



(3)



(4)

47. To say that the relative humidity on a given day is 70 percent means that the air

(1) is composed of 70 percent water vapor
(2) holds 70 percent of its water vapor capacity
(3) contains 70 parts of water to 100 parts of dry air
(4) contains the same amount of water that it would contain at 70°F

48. If the amount of water vapor in the air increases, then the dew point of the air will

(1) decrease
(2) increase
(3) remain the same

49. During which part of the day is the relative humidity usually lowest?

(1) morning
(2) midafternoon
(3) evening
(4) late night

50. As the air temperature rises, the relative humidity

(1) increases
(2) decreases
(3) remains the same

51. Air with a temperature of 60°F and a relative humidity of 51 percent was warmed to a temperature of 70°F, but the relative humidity remained at 51 percent. How did the moisture content change?

(1) The moisture content decreased.
(2) The moisture content increased.
(3) The moisture content remained the same.

52. Which statement best explains why the wet-bulb thermometer of a sling psychrometer usually shows a lower temperature than the dry-bulb thermometer?

(1) Water evaporates from the wet-bulb thermometer.
(2) Water vapor condenses on the wet-bulb thermometer.
(3) The air around the wet-bulb prevents absorption of heat.
(4) The air around the dry bulb prevents absorption of heat.

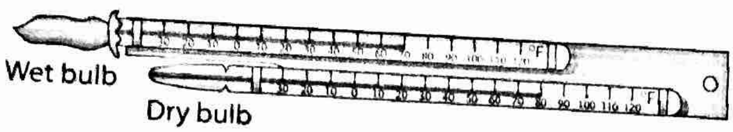
53. When the dry-bulb temperature is 20°C, and the wet-bulb temperature is 16°C, the relative humidity is

(1) 42 percent
(2) 62 percent
(3) 66 percent
(4) 69 percent

54. The dry-bulb temperature is 20°C. The wet-bulb temperature is 17°C. What is the dew point?

(1) 12°C (2) 13°C (3) 14°C (4) 15°C

Base your answers to questions 55 and 56 on the weather instrument shown in the following diagram.



55. What are the equivalent Celsius temperature readings for the Fahrenheit readings shown?

(1) wet 21°C, dry 27°C
(2) wet 26°C, dry 37°C
(3) wet 70°C, dry 80°C
(4) wet 158°C, dry 176°C

56. Which weather variables are most easily determined by using this weather instrument and the *Earth Science Reference Tables*?

(1) air temperature and wind speed
(2) visibility and wind direction
(3) relative humidity and dew point
(4) air pressure and cloud type

57. Which process most directly results in cloud formation?

(1) condensation
(2) transpiration
(3) precipitation
(4) radiation

58. At which temperature could water vapor in the atmosphere change directly into solid ice crystals?

(1) 20°F (2) 40°F (3) 10°C (4) 100°C

59. Which statement best explains how atmospheric dust particles influence the water cycle?

(1) Dust particles are the main source of dissolved salts in the sea.
(2) Dust particles increase the capacity of the atmosphere to hold water vapor.
(3) Dust particles increase the amount of evaporation that takes place.
(4) Dust particles provide surfaces on which water vapor can condense.

60. Atmospheric transparency is most likely to increase after

(1) volcanic eruption
(2) forest fires
(3) industrial activity
(4) precipitation

Air Masses and Fronts

Much of the weather of the contiguous United States is the result of the invasion of air masses and their interactions at their boundaries. An **air mass** is a large body of air in the troposphere with similar characteristics of pressure, moisture, and temperature.

Characteristics of Air Masses

An air mass forms when a large mass of air remains stationary over a part of Earth's surface for a period of time and thus acquires some of the characteristics of that surface. The geographic regions in which air masses are formed are called source regions. The source regions for the air masses that affect weather in the United States are shown in Figure 7-17.

If the source region is at a high latitude, the air mass will have a low temperature; if it is at a low latitude, the air mass will have a high temperature. If the source region is land, the air mass will be dry; if it is water, the air mass will be moist. The symbols used for the various