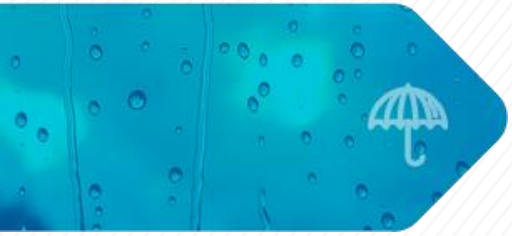
Introduction to Meteorology

08 Humidity

Introduction

Water vapor in the atmosphere varies from 0.1% to 4% per volume and forms a very small portion of the atmosphere. But water vapor is very important in the atmosphere. The general term "Humidity" is used to express the amount of water vapor. We will discuss various methods of expressing and measuring the amount of water vapor in the atmosphere.

Contents



1. Types of humidity
2. Measuring humidity

Learning objectives

1. Understand and explain how to express humidity.
2. Understand and explain how to measure humidity

Learning Activities

1. Types of humidity

Suppose that the air parcel is near the sea level and the pressure inside it is 1000hPa. Total air pressure inside the air parcel is equal to the sum of the pressure of the individual gases. When the total pressure is 1000 hPa, the pressure of nitrogen is 780 hPa, oxygen is 210 hPa, and water vapor is 10hPa. Water vapor pressure occupies only a small portion of the total pressure.

If the conditions are all the same, the larger the number of air molecules in a parcel, the greater the total pressure. For example, pressure increases as more air is blown into the balloon, total water vapor pressure also increases as the number of molecules of water vapor increases. Therefore, the water vapor pressure is a very suitable measurement unit for quantifying the total amount of water vapor in the atmosphere. The fact that the actual vapor pressure is high is the evidence that the number of water vapor molecules is large and vice versa.

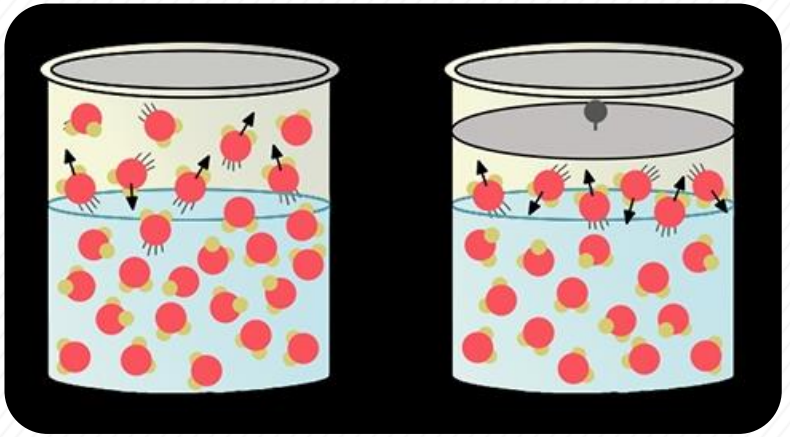
Learning Activities

1. Types of humidity

1) Vapor Pressure

Actual vapor pressure refers to partial pressure of water vapor to the total pressure of air, and saturation vapor pressure describes how much water vapor is necessary to make the air saturated at any given temperature. In other words, saturation vapor pressure is the pressure that the water vapor molecules would exert if the air were saturated with vapor at a given temperature.

Imagine the evaporation of molecules at the surface of the water. When the air is saturated, the number of molecules escaping from the water surface equals the number returning. As the number of fast-moving molecules increases proportionally with the temperature, the number of molecules escaping per second increases as well. To maintain equilibrium, this causes an increase in the number of water vapor molecules in the air above the liquid. At higher temperature, it takes more water vapor to saturate the air. More vapor molecules exert a greater pressure. Therefore, the saturated water vapor pressure is mainly dependent on temperature



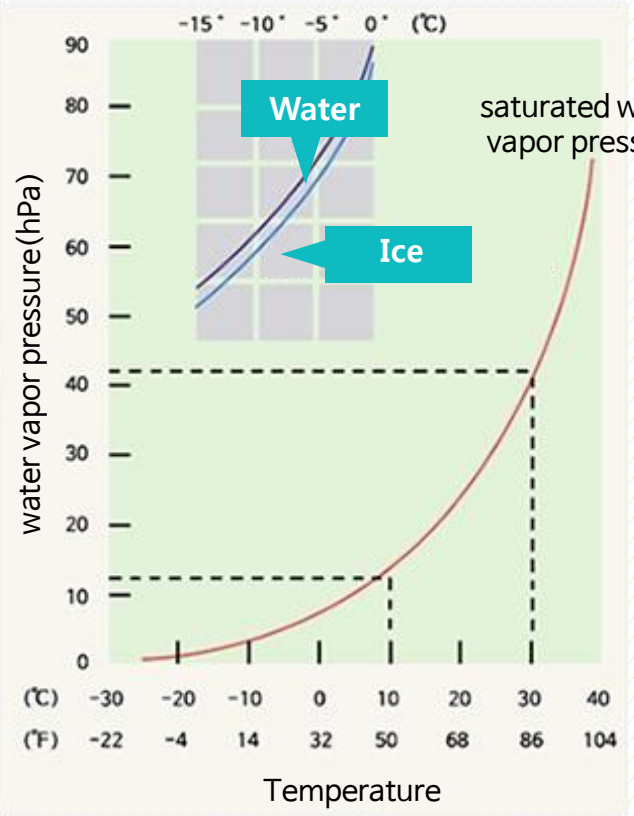
〈Molecules evaporating from a water surface〉

※ Source: Atmospheric Environment Science (Min, Kyung Deok et al, Sigma Press) p20

Learning Activities

1. Types of humidity

This graph shows that the saturated vapor pressure at 10˚C is about 12 hPa compared to 42hPa at 30˚C.



※ Source: Atmospheric Environment Science (Min, Kyung Deok et al., Sigma Press) p71

Learning Activities

1. Types of humidity

2) Relative humidity (RH)

The ratio of the amount of water vapor contained in the actual air to the maximum amount of water vapor required for saturation at a given temperature is called the relative humidity and is usually expressed as a percentage

$$\mathrm{H}\ (\%) = \frac{\text{Actual vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

Because the saturation vapor pressure depends on temperature, the relative humidity can change even if the water vapor pressure is constant. Relative humidity is the most common way to express atmospheric humidity, but it does not represent actual water vapor in the atmosphere. Instead, it measures how close the air is to saturation. The change in relative humidity depends on the change of water vapor and temperature in the air. Since the change in the amount of water vapor in the atmosphere during the day is small, the temperature mainly affects the daily change in relative humidity. Relative humidity can also be approximated by mixing ratio and saturation mixing ratio as follows. Relative humidity refers to the ratio of the air's water vapor content to its capacity in a given temperature.

$$\mathrm{RH}(\%) = \frac{\mathrm{r}}{r_s(T)} \times 100$$

Learning Activities

1. Types of humidity

Air with a relative humidity of 50% contains water vapor that is half the amount of water vapor required for saturation. Air with a relative humidity of 100% is saturated, and a condition when air's relative humidity is greater than 100% is called supersaturation. Since the relative humidity is proportional to the water vapor content of the air, it can change either of two ways: by changing the air's water vapor content or by changing the air temperature because the amount of water vapor required for saturation is a function of temperature.

Let's look at the actual water vapor pressure change due to the change in water vapor content. The water vapor pressure and relative humidity of the air will increase as the amount of water vapor increases, assuming that the temperature remains constant. Relative humidity increases as the actual water vapor pressure approaches saturation water vapor pressure and the air approaches saturation. Conversely, if the amount of water vapor is reduced, the water vapor pressure and relative humidity of the air will be lowered. In summary, the addition of atmospheric water vapor increases the relative humidity without changing the temperature, and conversely, when the water vapor is removed, the relative humidity decreases.

Relative humidity varies with temperature, because of the change in saturation vapor pressure. The higher the temperature, the higher the saturation water vapor pressure, which increases the water vapor capacity of the air. With no change in the water vapor content, the relative humidity decreases. On the other hand, as the temperature decreases, the saturation water vapor pressure decreases and the relative humidity increases. In other words, without change in the water vapor content, the relative humidity decreases as the temperature rises, and vice versa.

Learning Activities

1. Types of humidity

Due to the little change in atmospheric vapor content within a day, daily change of relative humidity is mainly affected by temperature change. Relative humidity increases as the air cools at night, and the relative humidity is highest when the temperature is lowest early in the morning. As the temperature increases during the day, the relative humidity decreases and reaches its minimum in the afternoon. Changes in relative humidity are important in determining the amount of evaporation from vegetation and wet surfaces. If you water lawn on a warm afternoon, when the relative humidity is low, much of the water will evaporate quickly instead of soaking into the ground. In the evening, the effectiveness of watering will increase. Higher humidity rather than higher temperature often makes the discomfort index higher.

※ Source: http://newdle.noonnoppi.com/xmlView.aspx?xmldid=39805

Learning Activities

1. Types of humidity

In warm weather, our body cools itself though evaporation of sweat. When the air temperature is high and relative humidity low, sweat evaporates quickly, often making us feel that the air temperature is lower than it really is. However, when both the temperature and relative humidity are high, body moisture does not readily evaporate, instead, we feel hot and sticky.

A measure of how cool the skin can become is called the wet-bulb temperature. It is the lowest temperature that can be reached by evaporating water into the air. On hot days when the wet bulb temperature is low, rapid evaporation takes places at the skin surface. As the wet-bulb temperature gets close to the air temperature, the cooling will slow down and the skin temperature will rise. If the wet-bulb temperature exceeds the skin temperature, no net evaporation occurs, and the body temperature can rise rapidly. Fortunately, wet-bulb temperature is usually lower than skin temperature.

Learning Activities

1. Types of humidity

3) Absolute Humidity (AH)

Absolute humidity is the total mass of water vapor present in a given volume of air.

$$\mathrm{AH}(\%) = \frac{\text{mass of the water vapor } (g)}{\text{volume of air } (m^2)}$$

The mass of vapor contained in the volume of air is denoted by gram (g). As air moves from one place to another, changes in pressure and temperature will cause changes in air volume. When the parcel's volume changes, the absolute humidity changes even if there is no change in the amount of water vapor. Thus, absolute humidity cannot represent the moisture content of the moving parcel. Therefore, meteorologists generally prefer to use mixing ratio when expressing the water vapor content in the air.

Learning Activities

1. Types of humidity

4) Mixing Ratio (r)

The mixing ratio is ratio of the mass of water vapor to the mass of dry air.

$$\mathrm{r} = \frac{mass\ of\ water\ vapor\ (g)}{mass\ of\ dry\ air\ (kg)} = \frac{m_v}{m_d}$$

As measured in mass units, the mixing ratio is not affected by changes in pressure or temperature. The mixing ratio the specific humidity are almost the same. This is because the amount of water vapor in the air (denominator) is very low, it shows a similar ratio. The possible maximum mixing ratio at a given temperature of the atmosphere is called the saturation mixing ratio.

Learning Activities

1. Types of humidity

5) Specific Humidity (q)

Specific humidity is the (dimensionless) ratio of the mass of water vapor to the total mass of the air.

$$\mathrm{q} = m\frac{ass\ of\ water\ vapor\ (m_v)t}{otal\ mass\ of\ the\ air\ (m)}$$

$$= \frac{m_v}{m_v + mass\ of\ the\ dry\ air\ (m_d)}$$

Unlike absolute humidity, it has the advantage that it remains constant when the air expands or compresses, as the mass does not change when, for example, 1kg of air expands. When the water vapor condenses during the expansion process, however, the specific humidity decreases. The maximum value of specific humidity at a given temperature is called saturation specific humidity.

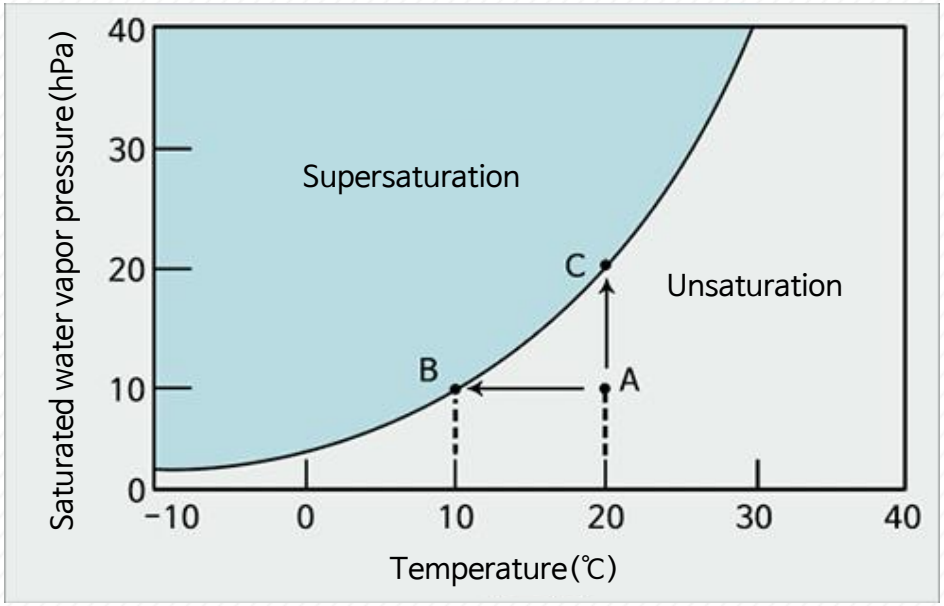
Learning Activities

1. Types of humidity

6) Dew-point temperature

Another important measure of humidity is the dew-point temperature. The dew point temperature is the temperature at which saturation would occur.

For being saturated, unsaturated air at point A must be cooled down to B. The dew-point temperature of this air parcel is therefore 10˚C. Unlike relative humidity, which measures air saturation, the dew-point temperature measures the actual water vapor content within the air parcel. It is directly related to the amount of water vapor in the air and is easy to measure. Dew-point temperature is one of the most useful methods of humidity measurement.



※ Source: Environmental Atmospheric Sciences 3rd edition (Kim, Kyung-Eak et al., Donghwa Technology) p79

Learning Activities

1. Types of humidity

How does dew-point temperature relate to relative humidity? The difference between the temperature and the dew-point temperature indicates whether the relative humidity is high or low.

If the difference between temperature and dew-point is large, the relative humidity is low. If the difference between the two is small, the relative humidity is high. When the temperature is equal to the dew point temperature, the air is saturated and the relative humidity is 100%. However, under a certain condition, we may feel the air to be dry. For example, in polar regions, the relative humidity is 100% because of the equal temperature and dew-point temperature. The relative humidity is much lower in the desert where the difference between temperature and dew-point temperature is large. However, because dew-point temperature is a measure of the amount of water vapor in the atmosphere, there is more water vapor in the desert atmosphere with relatively high dew-point temperature. Thus, the desert atmosphere has higher vapor density and higher absolute humidity. Specific humidity and mixing ratio are also higher. That is why the polar atmosphere with high relative humidity is often said to be dry.

Learning Activities

2. Measuring humidity

Water vapor is mixed with other gases in the atmosphere, and its content is very small, requiring very complex and sophisticated equipment for measurement

Learning Activities

2. Measuring humidity

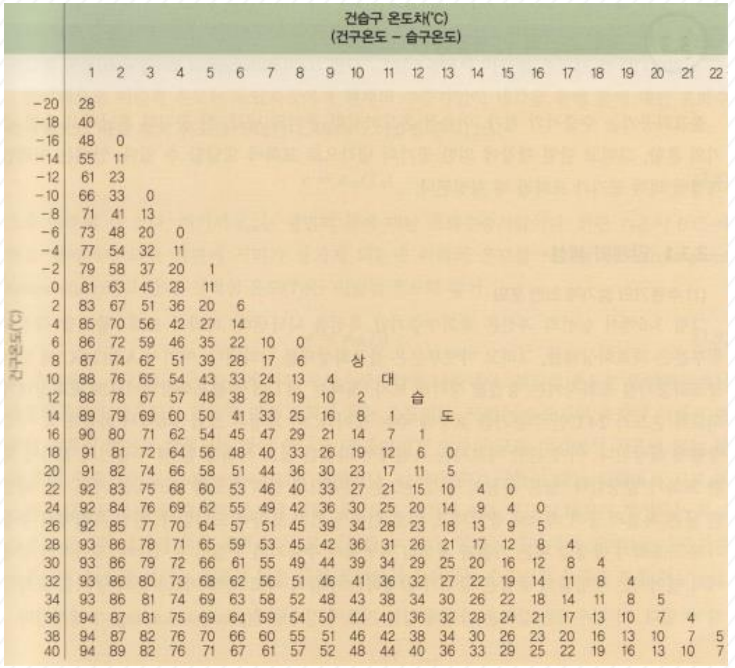
1) Psychrometer

The simplest and most widely used instrument for measuring humidity is a hanger type Psychrometer, which consists of two liquid-in-glass thermometers mounted side by side, one of which has a wick covering the bulb. The wick-covered thermometer (called the wet bulb) is dipped in clean water, whereas the other is kept dry. Both thermometers are ventilated by being whirled. If the air is unsaturated, latent heat is absorbed, and water evaporates from the wet bulb lowering temperature. After circulating the air for a while, the amount of heat loss due to the evaporation is canceled by the sensible heat from the ambient. After that, the wet bulb maintains a constant temperature no matter how long the equipment whirls.

The temperature indicated by the dry thermometer is called the dry-bulb temperature, and the minimum temperature indicated by the wick-covered thermometer is called the wet-bulb temperature. The difference between dry-bulb and wet-bulb temperature is known as the wet-bulb depression. A small depression indicates that little evaporation of water vapor is possible, therefore the air is close to saturation and the relative humidity is high. If there is no depression, the dry and wet bulb, and the dew-point are the same, and the air is saturated and relative humidity is 100%. A large depression indicates that a great deal of water can evaporate into the air and that the relative humidity is low. Consequently, the difference between the dry-bulb and wet-bulb temperature is large.

Learning Activities

2. Measuring humidity



건습구 온도차(℃)
(건구온도 – 습구온도)

건구온도(℃)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
-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																
6	86	72	59	46	35	22	10	0														
8	87	74	62	51	39	28	17	6		상												
10	88	76	65	54	43	33	24	13	4		대											
12	88	78	67	57	48	38	28	19	10	2		습										
14	89	79	69	60	50	41	33	25	16	8	1		도									
16	90	80	71	62	54	45	47	29	21	14	7	1										
18	91	81	72	64	56	48	40	33	26	19	12	6	0									
20	91	82	74	66	58	51	44	36	30	23	17	11	5									
22	92	83	75	68	60	53	46	40	33	27	21	15	10	4	0							
24	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4	0						
26	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9	5						
28	93	86	78	71	65	59	53	45	42	36	31	26	21	17	12	8	4					
30	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16	12	8	4				
32	93	86	80	73	68	62	56	51	46	41	36	32	27	22	19	14	11	8	4			
34	93	86	81	74	69	63	58	52	48	43	38	34	30	26	22	18	14	11	8	5		
36	94	87	81	75	69	64	59	54	50	44	40	36	32	28	24	21	17	13	10	7	4	
38	94	87	82	76	70	66	60	55	51	46	42	38	34	30	26	23	20	16	13	10	7	5
40	94	89	82	76	71	67	61	57	52	48	44	40	36	33	29	25	22	19	16	13	10	7

※ Source: Environmental Atmospheric Sciences 3rd edition
(Kim, Kyung-Eak et al., Donghwa Technology) p77

Using the table above, relative humidity can be obtained by reading the wet-bulb depression temperature.

Learning Activities

2. Measuring humidity

2) Ventilated psychrometer and hygrometer

Ventilated psychrometer is a psychrometer in which the ventilation is provided by a suction fan, so that you don't need to hang the thermometer.

Hygrometer consists of a long rod of two metals and a rotating cylinder to keep a record of temperature and humidity.

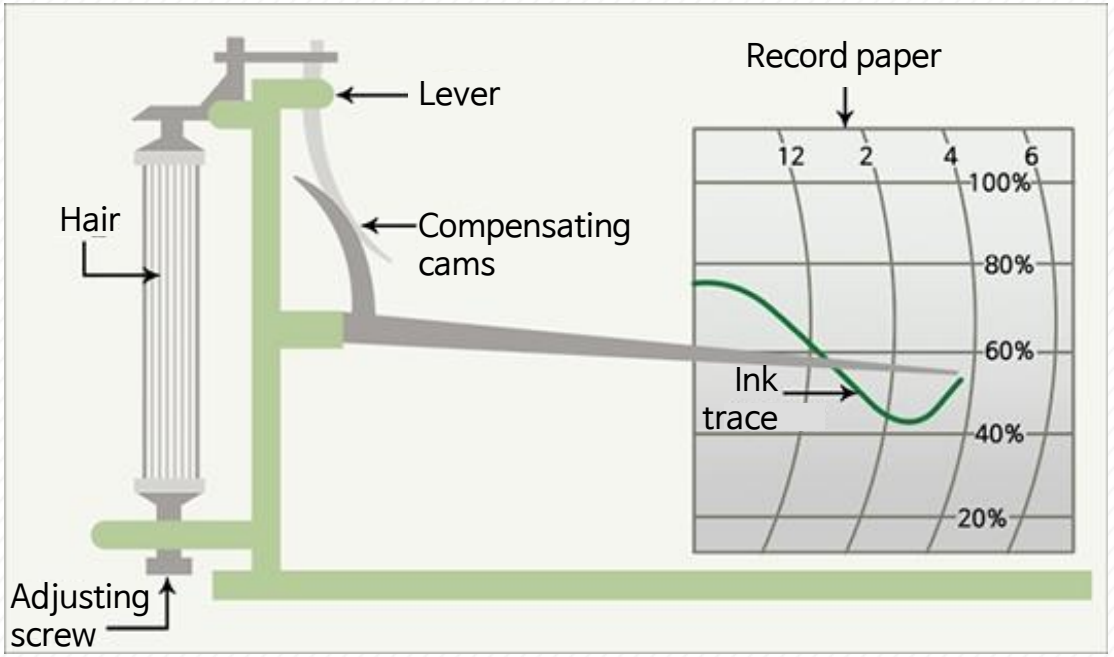
Learning Activities

2. Measuring humidity

3) Hair hygrometer

Hair hygrometer can read directly without using a table and works by the principle that the length of the hair changes proportionally to the change of the relative humidity. Hair increases with increasing relative humidity and decreases with lower relative humidity.

Strands of air with oil removed are attached to a system of levers. A small change in hair length is magnified by a linkage system and transmitted to a dial calibrated to show relative humidity, which can be recorded on a chart. Hair hygrometers, however, are not as accurate as a psychrometer. Therefore, it requires frequent testing and calibration. It also takes long time to respond to humidity changes, especially at low temperatures.



※ Source: Atmospheric Environment Science (Min, Kyung Deok et al., Sigma Press) p75

Learning Activities

2. Measuring humidity

4) Others

The electric hygrometer has a flat plate coated with a film of carbon. When an electric current is sent across the plate, water vapor gets absorbed, and the electrical resistance of the carbon coating changes. These changes are converted into relative humidity. This instrument is widely used in radiosonde, which collects meteorological data at different altitudes. In an infrared hygrometer, the relative humidity is determined by measuring the amount of infrared energy absorbed by water vapor in the air. The dew-point hygrometer measures the vapor pressure,

Summary

1. Types of humidity

- Humidity is the degree to which water vapor is contained in the atmosphere, which can be expressed in several ways
  - Water vapor pressure: refers to the partial pressure of water vapor in the total air pressure, and the water vapor pressure is a suitable unit for measuring the total amount of water vapor.
  - Relative humidity: The ratio of the amount of water vapor contained in the actual air to the maximum amount of water vapor required for saturation at a given temperature is called the relative humidity and is usually expressed as a percentage. Even if the water vapor pressure is constant, the saturation water vapor pressure changes with the temperature, so does the relative humidity. Changes in relative humidity depend on the amount of water vapor and temperature in the air parcel.

$$\text{RH}\ (\%) = \frac{\text{Actual vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

  - Absolute humidity: The mass of water vapor contained in a given volume of air, usually expressed in gram (g). When the parcel's volume changes, the absolute humidity changes even if the amount of water vapor remains constant.

$$\text{AH}(\%) = \frac{\text{mass of the water vapor}\ (g)}{\text{volume of air}\ (m^2)}$$

Summary

1. Types of humidity

- Humidity is the degree to which water vapor is contained in the atmosphere, which can be expressed in several ways
  - Mixing Ratio: the ratio of the mass of water vapor to the mass of dry air. As measured in mass units (g/kg), the mixing ratio is not affected neither by changes in pressure nor temperature.

$$\mathrm{r} = \frac{mass\ of\ water\ vapor\ (g)}{mass\ of\ dry\ air\ (kg)} = \frac{m_v}{m_d}$$

  - Specific humidity is the (dimensionless) ratio of the mass of water vapor to the total mass of the air.

Summary

2. Measuring humidity

- Psychrometer
  - It consists of two liquid-in-glass thermometers mounted side by side, one of which has a wick covering the bulb.
  - It measures the relative humidity from the difference between dry-bulb temperature and wet-bulb temperature
- Hair Hygrometer
  - Hair hygrometers works by the principle that the length of the hair changes proportionally to the change of the relative humidity
  - Strands of air with oil removed are attached to a system of levers.
  - A small change in hair length is magnified by a linkage system and transmitted to a dial calibrated to show relative humidity, which can be recorded on a chart.
- Electric hygrometer
  - The electric hygrometer has a flat plate coated with a film of carbon. When an electric current is sent across the plate, water vapor gets absorbed resulting in the change of electrical resistance of the carbon coating. These changes are converted into relative humidity.