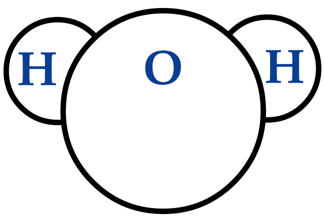
Atmospheric Water Vapor and its Importance

Overview

The atmosphere is primarily composed of nitrogen and oxygen. In dry air, these gases comprise about 78% and 21% of the atmosphere, respectively, by volume, leaving about 1% for all other gases, including argon, carbon dioxide, and ozone. However, the atmosphere is not completely dry; it typically contains 0 to 4% water vapor, concentrated near the earth's surface. It is this small amount of water vapor that greatly affects the weather.



Water vapor is simply water (H_2O) in its invisible gaseous form. It readily exists in Earth's atmosphere at temperatures cooler than the boiling point of water, even at temperatures below freezing. Water vapor is removed from air primarily by condensation and added to air primarily by evaporation and transpiration.

Atmospheric water vapor has many important effects on the weather and climate of Earth. It is the most important "greenhouse gas" in the atmosphere, trapping enough warmth for life to exist. Its presence is essential for clouds and precipitation to form and, hence, it is a vital component of Earth's water cycle. Its phase changes (from gas to liquid or vice versa, for example) produce significant changes in temperature, either adding energy to or removing energy from the atmosphere.

Condensation
- Water vapor → liquid water
- Energy released to surroundings
- A warming process

Evaporation
- Liquid water → water vapor
- Energy required from surroundings
- A cooling process

Evaporation and Condensation

Evaporation is the process by which a liquid is transformed into a gas. Conversely, condensation is the process by which a gas becomes a liquid. Energy is exchanged during both of these processes. The energy that is released or absorbed by water vapor during these phase changes is called *latent heat*.

When liquid water evaporates, energy is required to separate the molecular bonds which hold the water molecules close together in liquid form. This energy is removed from the nearby environment, whether that be the air or an object onto which the liquid water is attached. For example, when you step out of the shower into a drier environment, your skin suddenly feels cooler. This physical sensation is a result of the evaporation of the water on your skin into the air. Heat is taken from your body to change the water from liquid to gas. Hence, *evaporation is a cooling process.*

Fun Fact

Ninety-seven percent of Earth's water resides in the oceans. Only 0.0012% of Earth's water is in the atmosphere.

When water vapor condenses into liquid water, energy is released to the environment. In the atmosphere, this energy causes an increase in the air temperature in the region where condensation occurs. Hence, *condensation is a warming process.* As a result, the air becomes more buoyant, because warmer air is less dense than cooler air. The heating of the air has a significant impact on thunderstorm development and enhancement, adding to the thunderstorm's updraft.

On a molecular level, water molecules on the surface of liquid water (e.g., the ocean, a puddle, a raindrop in the air or on a leaf) that have enough energy will escape from the surface of the liquid and become a gas (that is, they will evaporate). Water molecules in the air that do not have enough energy to continue being part of the gaseous air will condense onto the surface of the liquid water. This exchange of molecules between gas and liquid occurs regularly at the temperatures and pressures common to Earth's atmosphere.

Saturation (of air)
The presence in air of the most water vapor possible under existent pressure and temperature.

If more water molecules evaporate from the liquid surface than condense onto it, the air is said to be *unsaturated*. If every molecule that evaporates from the liquid surface is accompanied by another molecule that condenses on the liquid, the air is said to be *saturated*. Hence, when air is saturated, there is a balance between the number of water molecules condensing and the number evaporating.

Water Vapor Content and Air Temperature

The amount of water vapor that can be maintained in the air at saturation changes depending on the air temperature. Because energy is required to allow water molecules to escape liquid form to become a gas, the cooler the air temperature, the lesser the energy available for evaporation to occur.

Fun Fact

A molecule of water will stay in Earth's atmosphere for an average duration of 10-12 days. In contrast, a molecule of water will remain in the ocean for an average of 3600 years.

Conversely, the warmer the air, the more the energy available for evaporation and, hence, more water molecules are able to evaporate into the air.

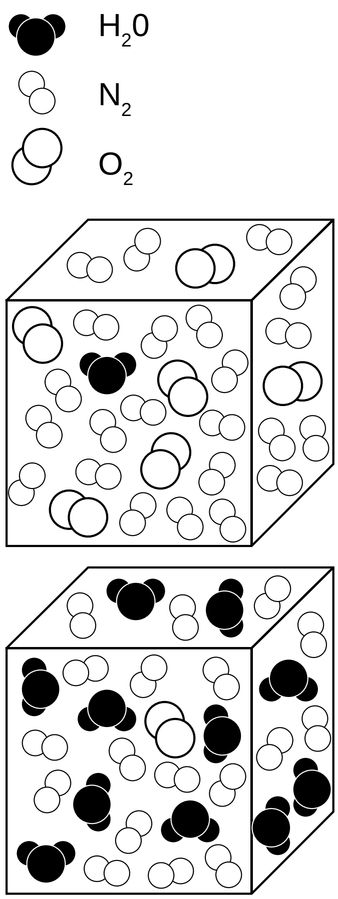
This point is vital to understanding atmospheric water vapor. *The warmer the air, the larger the number of water vapor molecules can be mixed into the air before saturation occurs. The cooler the air, the smaller the number of water vapor molecules can be mixed into the air before saturation occurs.*

Density of Moist Air versus Dry Air

If asked, few people would conclude that moist air is less dense than dry air. Their reasoning would be that if you add water vapor to dry air, there will be more molecules in the volume and, thus, more mass in the volume.

However, to make appropriate comparisons, the pressure in the volume cannot change. So the addition of water vapor means the removal of some other molecule. Because air is primarily composed of nitrogen and oxygen, these are the two most likely molecules to be removed. Molecular nitrogen (N_2) has a molecular weight of 28 and molecular oxygen (O_2) has a molecular weight of 32. Water vapor, on the other hand, has a molecular weight of 18, substantially less than either nitrogen or oxygen.

So when water vapor takes the place of nitrogen or oxygen in a given volume of air, the mass of the entire volume decreases (see figure to the left). Because density is defined as the mass per unit volume, the density of the given volume also decreases. Thus *moist air is less dense than dry air* (at the same pressure).



Total molecular weight of top volume: 854

Total molecular weight of bottom volume: 734

Dew Point, or Dewpoint Temperature

Because of water vapor's importance, no weather forecaster would make a prediction without taking into account the amount of atmospheric water vapor. Hence, its measurement is as vital as that of air temperature and winds. One variable that is used as a measure of atmospheric water vapor is *dew point,* which is also called *dewpoint temperature.* The dew point is the temperature to which air must be cooled at constant pressure for saturation to occur.

Dew point is expressed in units of temperature (e.g., Celsius or Fahrenheit). In weather forecasting, a dewpoint temperature near the ground of 55˚F and higher is considered adequate for severe thunderstorms to form. Dew points of 65˚F and higher are desirable before thunderstorms are capable of producing excessive rainfall. Those of 75˚F and higher are considered oppressive dew points. When the dewpoint temperature is lower than about 40˚F, the air is considered very dry. However, clouds can form at any dewpoint temperature as long as the air temperature decreases to equal the dew point.

To understand dewpoint temperature better, take a glass of ice water outside on a hot day. If beads of water condense on the outside of the glass, then the air next to the glass was cooled to its dew point, allowing the water vapor in the air to condense onto the outside of the glass.

Dewpoint temperature is an excellent measure of the actual amount of water vapor in the air. The higher the dew point, the more water vapor there is in the air. Conversely, the lower the dew point, the less water vapor there is in the air. For this reason, meteorologists use dew point as the primary variable to describe atmospheric moisture content.

Relative Humidity

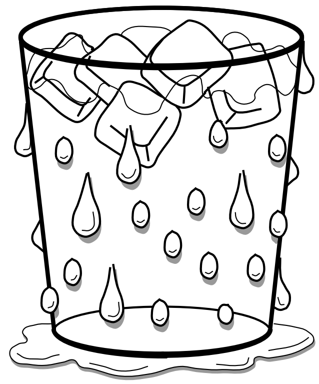
Relative humidity is the ratio of the amount of water vapor actually in the air compared to the maximum amount that can be mixed in air at that particular temperature. Hence, when the temperature changes, so does the relative humidity, even without changing the amount of water vapor in the air.

Relative humidity is expressed as a percentage. If the relative humidity were 0% (unrealistic near Earth's surface), there would be no water vapor in the air. When the relative humidity is 100%, the air is saturated and the air temperature and dewpoint temperature are equal. In this case, any decrease in the air temperature (thus decreasing the dew point because the relative humidity remains 100%) would result in water vapor condensing into cloud droplets or dew.

Because relative humidity is dependent on air temperature so strongly, it is not a good measure of the actual amount of water vapor in the air. However, relative humidity is a good indicator of the potential for evaporation to occur. When the relative humidity is high, little evaporation occurs. When the

Fun Fact

According to the U.S. Geological Survey, less than 1% of Oklahoma's water budget is consumed by humans in irrigation, industry, and household use.



Air next to the glass of ice water cools to its dew point. Water vapor in the air condenses on the glass.

Fun Fact

On July 28, 1995, the Oklahoma Mesonet measured oppressive conditions in eastern Oklahoma. Dew points in the 80's were measureed at 39 Mesonet sites, with the highest being 87° F at Broken Bow!

relative humidity is low, evaporation likely will occur, especially with moderate to strong winds and warm temperatures.

Dew Point versus Relative Humidity

Many people have difficulty in understanding the relationship between dew point and relative humidity. An analogy is appropriate to describe the differences (**Master #2A**).

Imagine that you have two glasses, each of which can contain 1 cup of liquid. You fill one full of water and the other you fill halfway with water. How can you describe the amount of water in each of the glasses? One way is to say that one glass contains 1 cup of water and the other contains 1/2 cup of water. Another way that is just as valid is to say that one glass is 100% full of water and the other is 50% full of water.

The first description of the amount of water in the glass is analogous to water vapor measurement using dew point. The second description is analogous to the measurement using relative humidity.

The importance of the difference is found when you find a second set of glasses. These two new glasses will contain 2 cups of liquid. Again, fill one full of water and the other fill halfway with water. The full glass now contains 2 cups of water and the other glass contains 1 cup. Or, similarly, one is 100% full and the other is 50% full.

Now compare the half full glasses. They are both 50% full, but they do not contain the same amount of water. One contains 1/2 cup of water and the second contains 1 cup. Analogously, two regions of air may have the same relative humidity but vastly different amounts of water vapor. Because warm air can sustain more water vapor mixed within it than cold air can, the warm air is analogous to the larger set of glasses; cooler air is analogous to the smaller set of glasses. Thus, meteorologists typically examine the dewpoint temperature rather than the relative humidity when making their forecasts.

Sources of Atmospheric Water Vapor

Weather forecasters try to predict the changes in the water vapor content of the air in order to enhance their forecasts of clouds, precipitation, and high and low temperatures. To predict these changes, forecasters are aware of the sources of moisture in and around their forecast area.

Most near-surface moisture results from evaporation over warm ocean waters. The moist air is blown over land by near-surface winds. Indeed, the moisture in the humid South and Southern Great Plains of the U.S. predominantly is blown by the wind, or is *advected*, from the Gulf of Mexico. Smaller sources of evaporation include lakes, rivers, irrigated fields, and wet soil. Although solar heating and warm temperatures enhance evaporation, the single most important aid to evaporation is strong winds. Sometimes strong winds also mix drier air from above toward the surface, lowering the moisture content of the air even while evaporation is adding moisture.

Plants have an important role in Earth's water cycle. They absorb water from the soil through their roots in order to remain healthy. As a source for atmospheric moisture, plants *transpirate*, exchanging carbon dioxide in the atmosphere for oxygen and water vapor. The rate of transpiration increases as a result of photosynthesis as plants become greener and healthier and as their water source is replenished with precipitation.

Diurnal Cycle of Dewpoint Temperature

During a quiescent warm day (e.g., autumn high pressure system), it is possible to observe a few characteristic changes in the dew point over a 24-hour period. After sunset, the air temperature decreases steadily throughout the night. If the air temperature cools to the dew point, dew will form on objects near the ground. The formation of dew will remove water vapor from the air; hence, the dewpoint temperature will decrease throughout the night after dew begins to form.

At sunrise, dew on the ground quickly evaporates, adding moisture to the air and increasing the dewpoint temperature. As the day gets warmer, the winds increase, creating a competing effect of increasing and decreasing moisture. First, warm temperatures and windy conditions increase evaporation at the surface. This effect tends to *increase* surface moisture. However, strong winds also mix the air from the ground upward into the atmosphere and move air from above toward the ground. Because the air aloft typically is drier than that near the surface, this effect tends to *decrease* surface moisture.

As the sun begins to set, the winds calm and the dewpoint temperature may rise as a result of continued evaporation and transpiration.

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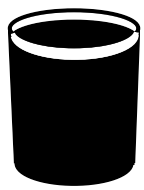
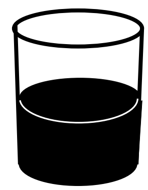
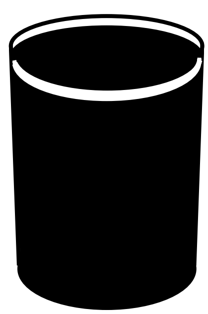
Analogy of Dewpoint Temperature vs. Relative Humidity



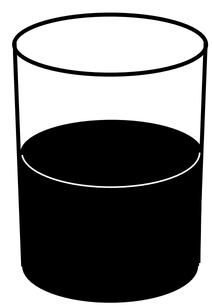
1 cup of water
100% full



1/2 cup of water
50% full



2 cups of water
100% full



1 cup of water
50% full