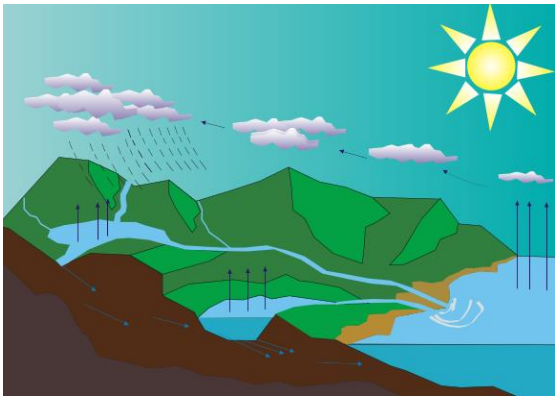
Water in the Atmosphere Learning Module



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Earth is unique among the planets in our solar system not because it has water, but because it has water in all three phases —liquid, solid, and gas. In this video lecture, we will discuss the role water plays in the earth-atmosphere system. [3]

Water on Planet Earth (6:15)

Video Lecture Notes [1, 2]

- Water is the most abundant liquid on our planet and its high heat capacity helps moderate our climate.
- 71% of the surface of the Earth is covered in water (the oceans), but the largest reservoir of water on Earth is found in the Earth's crust and mantle (10x more than in the oceans).
- On average, 67% of Earth's surface is covered with clouds, which are made of tiny liquid water droplets and ice crystals.
- When water changes between its liquid, solid and gas phases, an enormous amount of heat energy is either required or released. Water changing between gas, liquid, and solid is a **phase change**, or change of state.
- Water is more dense than ice, which is why ice floats in a glass of water.
- You CANNOT see water vapor - it is invisible, like all gases, to the naked eye.
- Steam is composed of small liquid water droplets, not water vapor.

Phase Changes of Water

The concepts in the next video lecture are crucial to understand the enormous amount of energy exchanged when water changes phase. This will be important when we study severe weather such as thunderstorms, floods, and hurricanes. The energy exchanged during a phase change of water in the atmosphere cause these amazing weather phenomena! [3]

Phase Change of Water (7:54)

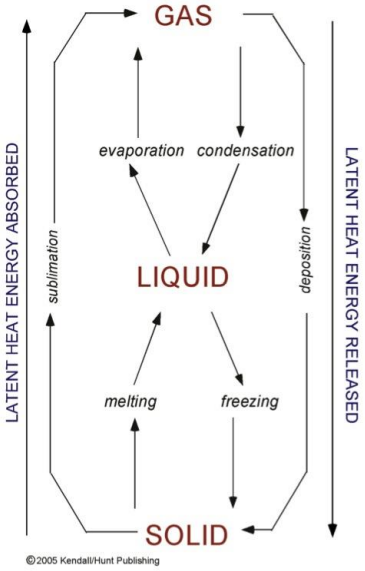
Created by Tyra Brown, Nicole Riemer, Eric Snodgrass and Anna Ortiz at the University of Illinois at Urbana-Champaign. 2015-2016. Supported by the National Science Foundation CAREER Grant #1254428.

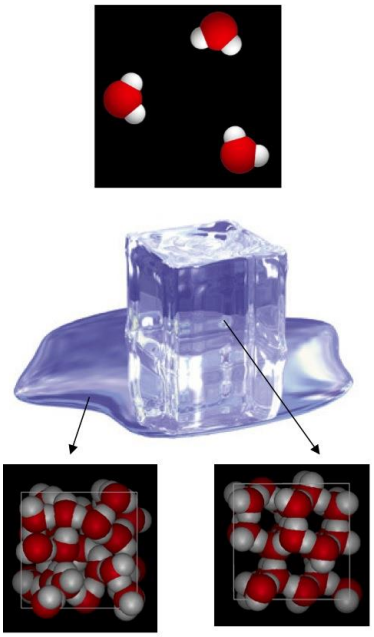
Phase change for water

Water can change form between gas, liquid and solid

To do so: Heat is required
or: Heat is released

Latent Heat = heat associated with phase change





Remember the boiling pot thought experiment

Source

Video Lecture Notes 1, 2, 4

- When water changes phase, energy (or heat) is required to aid in the phase change or is released once the change happens. This energy is called **latent heat**.
- The molecular structure of an ice crystal is hexagonal. Therefore all ice crystals are six-sided.
- Liquid water is the densest phase of water. This is why ice cubes float in a glass of water.

Energy Exchanges During Phase Changes

Now that we have discovered the energy exchange that happens when water changes phase, let's look at how this applies to soft drinks in the summer!

Warming and Cooling Processes (5:36)

Video Lecture Notes [1, 2]

- Evaporation is a cooling process (this is why your body sweats - evaporation of sweat cools you).
- Condensation is a warming process (when water condenses onto something, it warms it).

Measuring Moisture: Vapor Pressure

In this video lecture, we will tackle one of the more confusing parts of this course. Measuring water vapor content in the atmosphere is a tricky thing because it is an invisible gas. Be sure to watch this video in HD!

Water Vapor in the Atmosphere (8:28)

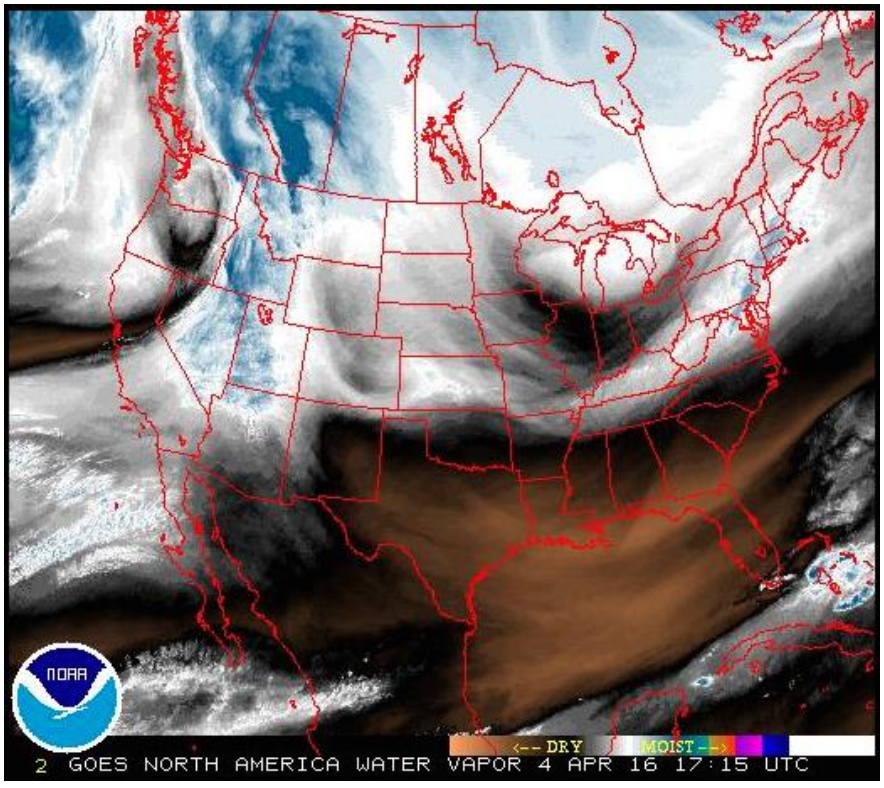


Figure 1. Satellite image showing the amount of water vapor in the atmosphere over the continental U.S. Brown shaded areas show where there are low water vapor concentrations (dry conditions) and white and blue shaded areas show high water vapor concentrations (moist conditions). Source

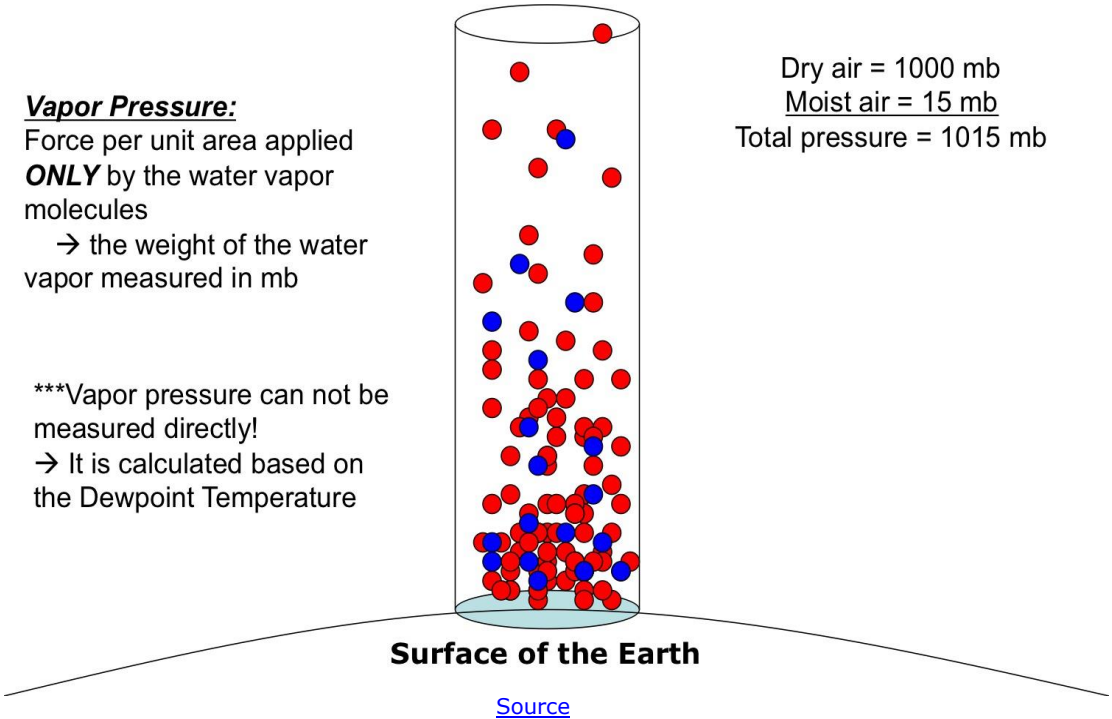
Measuring Moisture: Vapor Pressure

Dry air O_2 and N_2
Water Vapor H_2O

Total air pressure is the sum of the pressures from individual gasses (Dalton's Law)
→On Earth, the primary contributors to the dry air pressure are O_2, N_2 and Argon
→ Since water vapor is a highly variable gas in space and time, it can contribute a significant amount to the total air pressure.

Vapor Pressure:
Force per unit area applied ***ONLY*** by the water vapor molecules
→ the weight of the water vapor measured in mb

***Vapor pressure can not be measured directly!
→ It is calculated based on the Dewpoint Temperature



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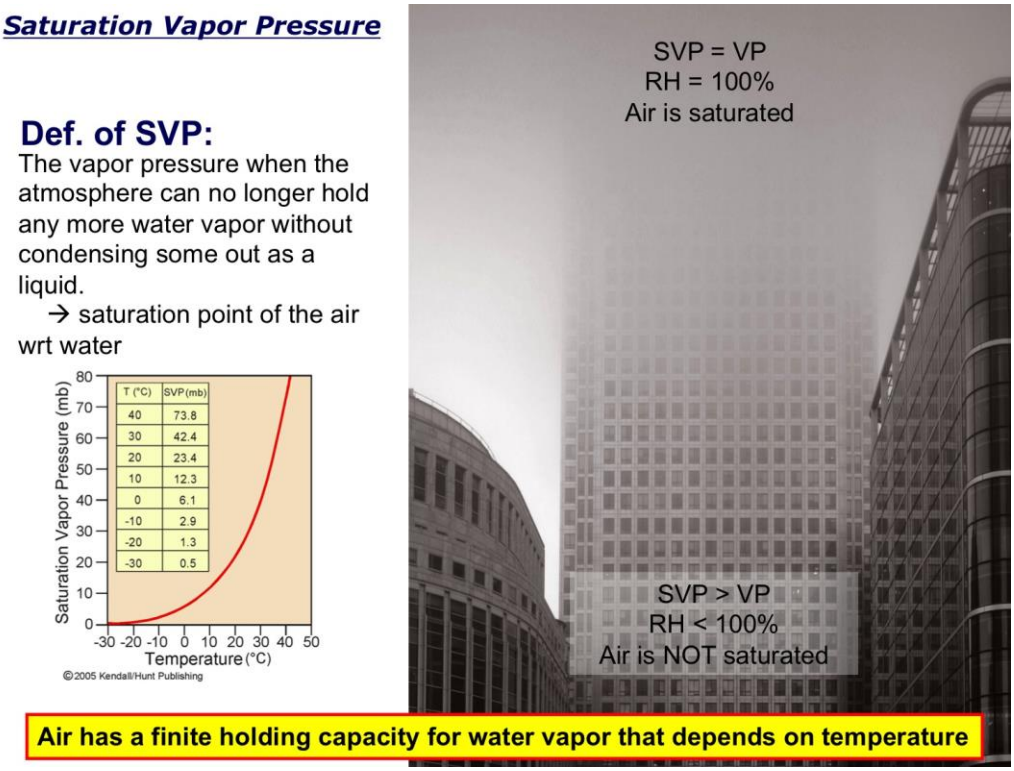
Video Lecture Notes 3, 4

- **Vapor pressure** is the partial pressure of water vapor in the atmosphere (in other words, it is the force per unit area applied by the water vapor molecules).
- Measuring water vapor content in the atmosphere is done indirectly since we cannot actually measure the exact amount of water vapor in the air.
- It is impossible to measure the vapor pressure directly, BUT we can calculate it using the dewpoint temperature (T_d).
- The dewpoint temperature is directly related to the amount of water vapor in the air and thus, the vapor pressure. So, as the dewpoint temperature increases, the vapor pressure of the air also increases!

Measuring Moisture: Saturation Vapor Pressure

In the video lecture below, we will learn how to saturate the atmosphere with water vapor. As you watch this video, pay close attention to the relationship between the saturation vapor pressure and air temperature. Be sure to watch this video in HD!

Saturation Vapor Pressure (3:48)



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Video Lecture Notes 3, 4

- **Saturation vapor pressure** is defined as the vapor pressure when it is saturated with water vapor (i.e., the amount of water vapor necessary to saturate the air).
- Air temperature determines the saturation vapor pressure – the higher the temperature, the higher the saturation vapor pressure.
- The air is saturated when the air has a **relative humidity** (RH) of 100%. This occurs when the vapor pressure equals the saturation vapor pressure and the air temperature equals the dewpoint temperature (RH = 100%, VP = SVP, T = T_d).

Measuring Moisture: Relative Humidity and Dewpoint Temperature

The relative humidity is the most misunderstood and misused weather variable. To understand why, let's first look at its definition — **relative humidity** is the ratio of the actual amount of water vapor in the air to the maximum amount of water vapor that is possible at a given temperature. The mathematical definition of relative humidity is,

RH = (VP / SVP) x 100%

In these next two videos we will explore the meaning of the relative humidity.

Relative Humidity and Dewpoint Temperature (8:32)

Examples of Relative Humidity (2:59)

How to measure moisture?

Dew Point Temperature (T_d)

Definition:

The temperature to which the air must be cooled for condensation to begin (forms clouds, dew, frost and fog)

When the T is close to T_d = "humid" air
When the T is far from T_d = dry air

Relative Humidity

Definition:

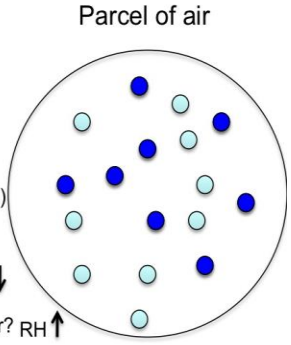
A measure of the actual amount of moisture in the air relative to its maximum capacity.

$$RH\% = \frac{VP}{SVP} * 100$$

To change the RH:
1. Add or subtract water vapor
2. Raise or lower the temperature

Simple example:
SVP = 12 spots (set by the T)
VP = 4 spots are full (set by the Td)
RH = (4/12)*100 = 33%

What if we heat the air up? RH ↓
What it we cool it off? RH ↑
What if we add more water vapor? RH ↑



Source

Video Lecture Notes 3, 4

- **Dewpoint temperature** is the temperature at which the air must be cooled for condensation to begin.
- **Relative humidity** is the ratio of the actual amount of water vapor in the air over the air's maximum amount of water vapor.
- The relative humidity is relative to air temperature because warmer air has a greater capacity for water vapor.
- The relative humidity can be changed by adding/subtracting water vapor from the air OR increasing/decreasing the air temperature.

Pre-Class Activity [2, 3, 4]

Instructions: Before teaching about water on Earth and in the atmosphere, have the students answer the five questions below, followed by a thought question for in-class discussion between you and your students. If time permits, try a live demonstration of the collapsing can experiment!

1. Take a guess of the world records for the following precipitation rates!
    a. Most rainfall in 1 hour:
    b. Most rainfall in 1 day:
    c. Most rainfall in 1 year:

2. Which two variables must be equal for clouds to form?
    a. Temperature and pressure
    b. Dewpoint temperature and pressure
    c. Wind speed and pressure
    d. Temperature and dewpoint temperature

3. What does the dewpoint temperature tell us?
    a. How hot it is outside
    b. How much liquid water is in the air
    c. How many clouds are outside
    d. How much water vapor is in the air
    e. How much dew has formed on the grass

4. Which of the following occurs when the air reaches saturation?
    a. Water freezes into ice
    b. Ice melts into liquid water
    c. Water vapor condenses into liquid water

5. Which of the following is not true?
    a. Clouds are made of liquid water droplets.
    b. Clouds are made of water vapor.
    c. Clouds can form at the surface.
    d. All forms of precipitation come from clouds.
    e. Liquid water is more dense than ice.

Discussion Question: Water occurs in all three phases on Earth. Name some examples of where you might see each phase of water in the atmosphere and at the surface. You may want to review the water cycle during your discussion!

Collapsing Can Demonstration

In-Class Activity

Part 1. Multiple Choice (Circle One) 1, 2, 3, 4, 7

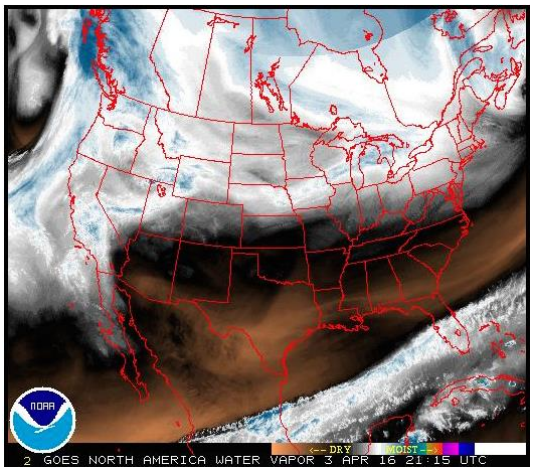
1. What percentage of the earth's surface is covered by water?
    a. 71%
    b. 95%
    c. 45%
    d. 50%

2. What type of energy is associated with phase changes of water?
    a. Sensible heat energy
    b. Radiative energy
    c. Thermal heat energy
    d. Latent heat energy

3. What is condensation?
    a. Water vapor → Liquid water
    b. Liquid water → Water vapor
    c. Liquid water → Ice
    d. Ice → Water Vapor

4. Which of the following is not true?
    a. Latent heat is released during condensation.
    b. Latent heat is absorbed during evaporation.
    c. Evaporation is a cooling process.
    d. Condensation is a cooling process.

5. Which of the five states marked on the map below has the highest water vapor concentrations?
    a. Michigan
    b. Texas
    c. Oklahoma
    d. South Carolina
    e. Missouri



Part 2. True/False (Circle One) 3, 4, 6

1.	Saturation vapor pressure increases as temperature increases.	T	F
2.	Dewpoint temperature decreases as vapor pressure decreases.	T	F
3.	Saturation occurs when vapor pressure equals the temperature.	T	F
4.	Clouds form when RH = 100%.	T	F
5.	Dewpoint is directly measured using a water barometer.	T	F

Part 3. Calculation 3

Instructions: Relative humidity (RH) is the ratio of the actual amount of water vapor in the air over the air's maximum holding capacity. Calculate the RH for the following days using the relative humidity calculator (be sure to enter temperatures in degrees Fahrenheit).

Relative Humidity Calculator

Day 1: Temperature = 78°F, Dewpoint Temperature = 55 °F → RH = _____

Day 2: Temperature = 78°F, Dewpoint Temperature = 60 °F → RH = _____

Day 3: Temperature = 85°F, Dewpoint Temperature = 60°F → RH = _____

Discussion Questions

1. Did the relative humidity increase or decrease between Days 1 – 2? What about between Days 2 – 3?

2. Based on the relationships of moisture in the atmosphere and your results above of how RH changes, relate how changes in temperature affect relative humidity. What about changes in dewpoint temperature? Explain why.

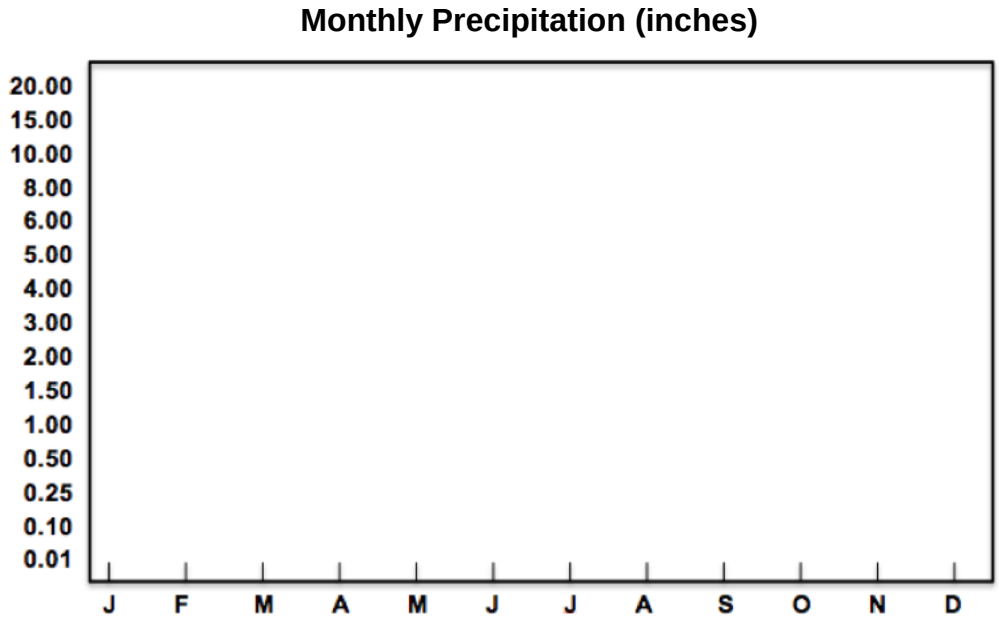
Take Home Assignment

Part 1. Annual Precipitation 3, 5

Instructions: Using the following link, record the monthly precipitation at your home. Below the map, change the timeframe of the archived precipitation data to 'Monthly' and record the monthly precipitation by viewing January – December of the previous year to see how precipitation patterns change in your area throughout the year. You may zoom in on the map and use the color bar on the right-hand side to determine the precipitation amount in inches. Record your results in the table provided. Once you have the monthly precipitation, plot the values and make a line graph below.

Monthly Precipitation Data

Month	Precipitation (inches)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	



Discussion Questions

1. Which month(s) have the most precipitation?

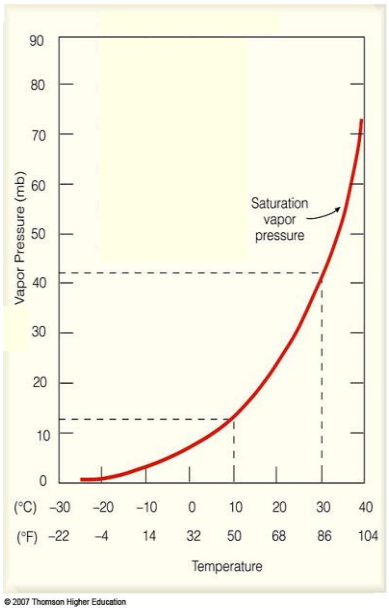
2. Which month(s) have the least precipitation?

3. What was the total precipitation from last year (in inches)?

Part 2. Vapor Pressure and Saturation Vapor Pressure [4, 5]

Instructions: Use the graph below to answer the following questions.

1. What is the saturation vapor pressure if the air temperature is 40°C (104°F)?
   a. 73%
   b. 42 mb
   c. 42°C
   d. 73 mb



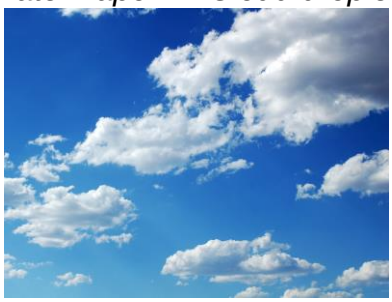
2. If the saturation vapor pressure is 40 mb and the vapor pressure is 20 mb, what is the relative humidity?
   a. 21%
   b. 42 mb
   c. 116°F
   d. 50%
   e. 200%

3. Which of the following is <u>not</u> true?
   a. The saturation vapor pressure is always greater than or equal to the vapor pressure.
   b. The vapor pressure is always greater than or equal to the saturation vapor pressure.
   c. Vapor pressure is the partial pressure due to water vapor in the atmosphere.
   d. Saturation occurs when vapor pressure is equal to the saturation vapor pressure.

Part 3. Matching [1, 2]

Instructions: In each of the following examples, write the phase change on the line and circle whether latent heat is absorbed or released during each process.

Water vapor → Cloud droplets



_____

absorbed / released

Ice → Liquid water

_____

absorbed / released

Raindrops → Frozen sleet

_____

absorbed / released

Water → Vapor

_____

absorbed / released

Water vapor → Liquid dew

_____

absorbed / released

Water Vapor → Frost

_____

absorbed / released

Student Evaluation 1, 2, 3, 4, 7

Instructions: After completing the lesson on water, please have the students answer the following questions below.

1. Which of the following is not true about dewpoint temperature?
    a. Dewpoint temperature is the temperature at which the air must be cooled for condensation to begin.
    b. If the temperature and dewpoint temperature are close, the air is humid.
    c. The dewpoint temperature is directly related to the amount of water vapor in the air.
    d. The dewpoint temperature is directly related to saturation vapor pressure.

2. If the classroom were heated from 70°F to 85°F, which variable would increase?
    a. Vapor pressure
    b. Dewpoint temperature
    c. Saturation vapor pressure
    d. Moisture
    e. Relative humidity

3. Which phase of water is the most dense?
    a. Ice
    b. Liquid water
    c. Water vapor

4. Clouds are made up of
    a. water vapor.
    b. liquid droplets.
    c. ice crystals.
    d. Both a & b
    e. Both b & c

5. Which of the following is not true about vapor pressure?
    a. Vapor pressure is the force per unit area applied by all phases of water.
    b. Vapor pressure cannot be measured directly.
    c. Vapor pressure is needed to calculate relative humidity.
    d. Vapor pressure is the partial pressure of water vapor in the atmosphere.
    e. Vapor pressure is calculated using the dewpoint temperature.

6. Saturation
    a. occurs when relative humidity is 150%.
    b. occurs when the temperature equals the dewpoint temperature.
    c. causes evaporation.
    d. occurs when vapor pressure equals the total air pressure.

7. Increasing the temperature results in a lower relative humidity. T F

8. Water vapor is invisible to the naked eye. T F

9. When water changes phase, energy in the form of latent heat is required to aid in the phase change or is released once the change occurs. Briefly explain whether the air temperature would increase or decrease slightly when a liquid cloud forms. Why? Recall clouds form when water vapor condenses into small cloud droplets.

10. Calculate the relative humidity if the vapor pressure is 42 mb and the saturation vapor pressure is 85 mb. Would you consider this dry or humid?

    a. RH = 0.494 mb, Dry
    b. RH = 2.024 mb, Dry
    c. RH = 2.024%, Dry
    d. RH = 49.41%, Dry
    e. RH = 202.38%, Humid
    f. RH = 49.41%, Humid

Common Core State Standards (CCSS) Initiative
To learn more, visit http://www.corestandards.org

Next Generation Science Standards (NGSS)
To learn more, visit http://www.nextgenscience.org

The following standards are met in this learning module:

1. **NGSS.MS-PS4-2**

MS-PS1-6. Chemical Reactions (Disciplinary Core Idea PS1.B)
Some chemical reactions release energy, others store energy.
Lecture: Phase Changes of Water, Energy Exchanges During Phase Changes; In-Class Activity: Part 1; Take Home Assignment: Part 3; Student Evaluation

2. **NGSS.MS-ESS2-4**

MS-ESS2-4. Earth's Systems (DCI ESS2.C)
Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation, crystallization, and precipitation, as well as downhill flows on land.
Lecture: Introduction, Phase Changes of Water, Energy Exchanges During Phase Changes; Pre-Class Activity; In-Class Activity: Part 1; Take Home Assignment: Part 3; Student Evaluation

3. **NGSS.MS-ESS2-5**

MS-ESS2-5. Weather & Climate (DCI ESS2.C)
The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns.
Lecture: Introduction, Phase Changes of Water, Measuring Moisture; Pre-Class Activity; In-Class Activity: Parts 1 – 3; Take Home Assignment: Part 1; Student Evaluation

4. **NGSS.MS-PS1-4**

MS-PS1-4. Structure and Properties of Matter (DCI PS1.A)
The changes of state that occur with variations in temperature and pressure can be described and predicted using models of matter.
Lecture: Phase Changes of Water, Measuring Moisture; Pre-Class Activity; In-Class Activity: Parts 1 & 2; Take Home Assignment: Parts 2 & 3; Student Evaluation

5. **CCSS.MATH.CONTENT.8.F.A.1**

Grade 8: Functions
Understand that a function is a rule that assigns to each input exactly one output. The graph of a function is the set of ordered pairs consisting of an input and the corresponding output.
Take Home Activity: Parts 1 & 2

6. **CCSS.ELA-LITERACY.RST.6-8.8**

Grade 8: Science and Technical Subjects
Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.
In-Class Activity: Part 2

7. **CCSS.ELA-LITERACY.RST.6-8.4**

Grade 6-8: Science and Technical Subjects
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific science or technical context relevant to grades 6-8 texts and topics.
Bolded text in lecture; In-Class Activity: Part 1; Student Evaluation

8. **CCSS.ELA-LITERACY.RST.6-8.7**

Grade 6-8: Science and Technical Subjects
Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
Video lectures; Take Home Activity: Part 1