ES 106 Laboratory # 6
MOISTURE IN THE ATMOSPHERE

Introduction

The first part of this laboratory examines the changes of state of water, how the water vapor content of the air is measured, and the sequence of events necessary to cause cloud formation. Water vapor, which is an odorless, colorless gas produced by the evaporation of water, comprises only a small percentage of the lower atmosphere (generally less than 4% by volume). However, it is an important atmospheric gas because it is the source of all precipitation, aids in the heating of the atmosphere by absorbing radiation, and is the source of latent heat (hidden or stored heat). No analysis of the atmosphere is complete without an investigation of water vapor in atmosphere, because it strongly influences humidity and precipitation. By observing, recording, and analyzing weather conditions, meteorologists attempt to define the principles that control the complex interactions that occur in the atmosphere.

The second part of this laboratory focuses on making weather observations. Weather plays an important role in our daily lives. We want to know what the weather will be, so that we can plan to bring umbrellas, put on sunscreen, drive cautiously, dress a certain way, or know when it will be nice for outdoor activities. People talk about weather. The weather is newsworthy. It can become headlines in local, regional, national, and international news reports. Weather forecasts are found in newspapers, on TV, on the radio, and a growing variety of websites on the internet. Weather forecasts provide short-term (hours, days or weeks) predictions of the state of our atmosphere.

Objectives

- Explain the adiabatic process and its role in cooling and warming the air.
- Calculate the temperature and relative humidity changes that take place in air as the result of adiabatic cooling.
- Make measurements of relative humidity and dewpoint temperature.
- Appreciate the role technology plays in helping make weather observations.

Useful Websites

- http://www.nws.noaa.gov
- http://www.eoearth.org/article/Atmospheric_humidity
- http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/atmospheric_moisture/humidity.html
- http://nova.stanford.edu/projects/mod-x/id-moist.html
- http://www.temperatures.com/dewpoint.html

Name________________________

Lab Day/Time_________________

Pre-lab Questions – Complete these questions before coming to lab.

1. Define the following terms:
   A. Relative Humidity

   B. Dew-point temperature

   C. Adiabatic temperature change

   D. Condensation

2. What is the difference between dry adiabatic lapse rate and wet adiabatic lapse rate? Which is greater? Why are they different?

3. If a beaker can hold 600 mL of liquid and it is 40% full, calculate the volume of liquid in the beaker. (Show formula for calculation, with units.)

4. If a beaker can hold 800 mL of liquid and it has 150 mL, calculate the percentage of the beaker that is filled. (Show formula, with units.)

Part A – Water Vapor Capacity of Air, Relative Humidity, and Dew-Point Temperature

Activity 1: Water Vapor Capacity of Air
The water vapor capacity of air is directly related to, and limited by, its temperature. The table below presents the water vapor capacity of a kilogram of air at various temperatures. Use the table to answer the following questions.

Table 1: Water vapor capacity of a kilogram of air at average sea level pressure.

Temperature (°F)	**Temperature (°C)**	**Grams of water vapor per kg of air (g/kg)**
- 40	- 40	0.1
- 22	- 30	0.3
-4	- 20	0.75
14	- 10	2
32	0	3.5
41	5	5
50	10	7
59	15	10
68	20	14
77	25	20
86	30	26.5
95	35	35
104	40	47

1. To demonstrate the relation between air temperature and water vapor capacity, prepare a graph by **plotting data from Table 1 in Figure 1**.

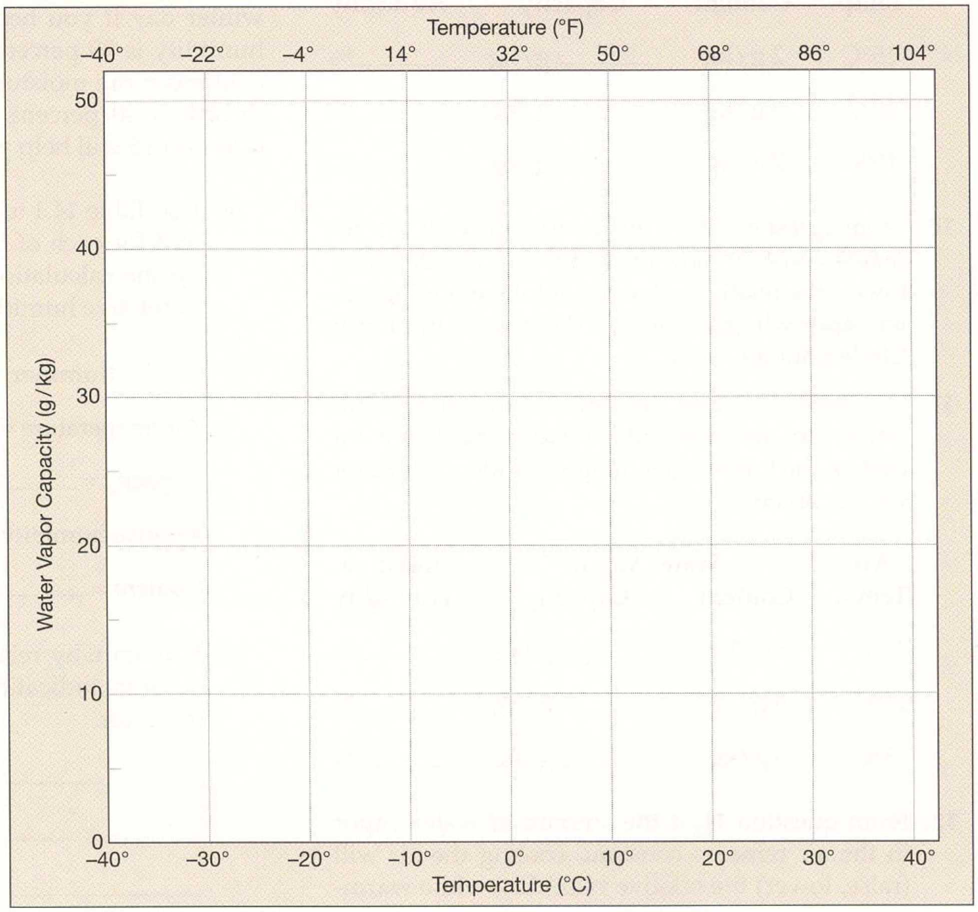

Figure 1: Graph of water vapor capacity of a kilogram of air versus temperature. Refer to Table 1 for values.

2. Read your graph to determine the water vapor capacity of a kilogram of air at each of the following temperatures	40º C: __________ grams/kilogram 68º F: __________ grams/kilogram 0º C: __________ grams/kilogram -20º C: __________ grams/kilogram

3. Read your graph to determine the effects described below. Write your answers in the areas to the right.	Change in water vapor capacity (increase/decrease)	Amount of change of the water vapor capacity in grams of a kilogram of air
Raising the air temperature from 10 to 15 °C		
Raising the air temperature from 35 to 40 °C		

4. Using your graph and the table, write a brief statement that relates the water vapor capacity of air to the temperature of air.

Activity 2: Relative Humidity and Dew Point Temperature

Relative humidity is the most common measurement used to describe water vapor in the air. In general, it expresses how close the air is to reaching its water vapor capacity. Relative humidity is the ratio of the air's water vapor content (amount actually in the air) to its water vapor capacity at a given temperature, expressed as a percent. The general formula is:

$$\text{Relative Humidity } (\%) = \left(\frac{\text{water vapor content}}{\text{water vapor capacity}}\right) \text{ x } 100\%$$

For example, the water vapor capacity of a kilogram of air at 25ºC would be 20 grams per kilogram. If the actual amount of water vapor in the air was 5 grams per kilogram (the water vapor content), the relative humidity would be calculated as follows:

$$\text{Relative humidity } (\%) = \left(\frac{5g / kg}{20g / kg}\right) \times 100 = 25\%$$

5. Use the Table 1 or Figure 1, and the general formula for relative humidity to determine the relative humidity for various water vapor contents of air at identical temperatures. Fill out Table 2, below

Table 2: Change in relative humidity with no change in temperature

Air Temp (°C)	Water Vapor Content	Water Vapor Capacity	Relative Humidity
15ºC	2 g/kg	g/kg	%
15ºC	5 g/kg	g/kg	%
15ºC	7 g/kg	g/kg	%

6. From Table 3, if the temperature of air remains constant, how does adding water vapor affect the relative humidity?

7. What effect will removing water vapor have on the relative humidity?

8. Use Table 1 and the general formula for relative humidity to determine the relative humidity for air at various temperatures with identical water vapor content. Fill out Table 3 below.

Table 3: Change in relative humidity with no change in water content

Air Temp (°C)	Water Vapor Content	Water Vapor Capacity	Relative Humidity
25ºC	5 g/kg	g/kg	%
15ºC	5 g/kg	g/kg	%
5ºC	5 g/kg	g/kg	%

9. So, if the amount of water vapor in the air remains constant, what effect will cooling or warming the air have on the relative humidity?

10. In the winter, air from outside is heated as it is brought into our homes. What effect does heating the air have on the relative humidity inside the home? What can be done to lessen this effect, while still being comfortable? (Hint: see Table 2 or 3)

11. Explain why a cool basement is humid (damp) in the summer. (Hint: see Table 3)

12. Write brief statements describing each of the two ways that the relative humidity of air can be changed. (Hint: see Table 2 and Table 3)

13. Use Table 1 to determine the water vapor content for each of the following situations. As you do the calculations, keep in mind the definition of relative humidity. Show calculations at right.

TABLE 4	**Relative humidity**	**Water Vapor Capacity**	**Water Vapor Content (g/kg)**
SUMMER Air temperature = 86º	20%	g/kg	
WINTER Air temperature = 50ºF	76%	g/kg	

14. One misconception concerning relative humidity is that it alone gives an accurate indication of the amount of water vapor in the air. For example, on a winter day if you hear on the car radio that the relative humidity is 90%, can you conclude that the air contains more moisture than a summer day that records a 40% relative humidity? Using the information in Table 4, explain why relative humidity does not give an accurate indication of the amount of water vapor in the air.

Refer to Table 1 for these questions

15. What is the dew-point temperature of a kilogram of air that contains 7 grams of water vapor?

Dew-point temperature =

________________________ °C

16. What is the dew-point temperature of a kilogram air that contains 10 grams of water vapor?

Dew-point temperature =

________________________ °C

17. What is the relative humidity of the air with 10 grams of water if its temperature is 25°C?

Relative humidity =

________________________ %

Activity 3: Measuring humidity using a psychrometer

Air is *saturated* when it has reached its water vapor capacity and contains all the water vapor that it can hold at a particular temperature. **In saturated air, the water vapor content equals its capacity**. The temperature at which air is saturated is called the *dew-point temperature*. Put another way, the dew point is the temperature at which the relative humidity of the air is 100%. Previously, you determined that a kilogram of air at 25°C, containing 5 grams of water vapor, had a relative humidity of 25%: not saturated. However, when the temperature was lowered to 5°C, the air had a relative humidity of 100% and was saturated. Therefore, 5°C is the dew-point temperature of the air in that example. Answer questions 15 and 16 at the top of the next page.

A psychrometer measures humidity by measuring the drop in temperature created by evaporation of water—the drier the air, the more evaporative cooling will occur. A thermometer with a dry bulb and a thermometer with its bulb inside a wet cloth are slung through the air. Air rushing over the wet cloth causes water to evaporate, and this cools the wet-bulb thermometer. Table 6 is used to convert the temperature difference between the wet and dry bulbs into relative humidity and Table 7 can determine dew-point temperatures from temperature measurements. Refer to Tarbuck and Lutgens, Earth Science 14th ed., p. 523-524, Fig. 17.9 for illustration of sling psychrometer; instructions for use are on the next page.

To operate the sling psychrometer:

- Wet the cotton cover on one thermometer with distilled water
- Sling it to allow evaporation to lower the temperature.
- After one minute, read the temperature on the wet bulb.
- Sling it for another minute and read the temperature again. If it is the same as the first reading, record that as the 'wet bulb temperature' in Table 5.
- If it is less than before, sling it for another minute, and read the temperature again.
- Continue doing this until the wet-bulb temperature reading is the same from one minute to the next.
- Determine the relative humidity and the dew-point temperature using Tables 6 and 7, on the following page.

TABLE 5: Sling Psychrometer Data	
Dry-bulb temperature (°C)	
Wet-bulb temperature (°C)	
Difference between dry- and wet-bulb temperatures (°C) (subtract)	
Relative humidity (from Table 6)	
Dew-point temperature (from Table 7)	

Explain the principle that governs the operation of a psychrometer for determining relative humidity.

Table 6: Relative Humidity determined by Wet Bulb Temp. Depression

Relative humidity (percent).

Dry bulb (°C)	Depression of Wet-Bulb Temperature (Dry-Bulb Temperature Minus Wet Bulb Temperature = Depression of the Wet Bulb)																					
	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														
10	88	76	65	54	43	38	24	13	4													
12	88	78	67	57	48	38	28	19	10	2												
14	89	79	69	60	50	41	33	25	16	8	1											
16	90	80	77	62	54	45	37	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

Dry-Bulb (Air) Temperature — Relative Humidity Values

* To determine the relative humidity, find the air (dry-bulb) temperature on the vertical axis (far left) and the depression of the wet bulb on the horizontal axis (top). Where the two meet, the relative humidity is found. For example, when the dry-bulb temperature is 20°C and a wet-bulb temperature is 14°C, then the depression of the wet bulb is 6°C (20°C − 14°C). From Table C-1, the relative humidity is 51 percent and from Table C-2, the dew point is 10°C.

Table 7: Dew-point temperature (C^o)

Dew-point temperature (°C)

Dry bulb (°C)	(Dry-Bulb Temperature Minus Wet-Bulb Temperature = Depression of the Wet Bulb)																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
−20	−33																					
−18	−28																					
−16	−24																					
−14	−21	−36																				
−12	−18	−28																				
−10	−14	−22																				
−8	−12	−18	−29																			
−6	−10	−14	−22																			
−4	−7	−12	−17	−29																		
−2	−5	−8	−13	−20																		
0	−3	−6	−9	−15	−24																	
2	−1	−3	−6	−11	−17																	
4	1	−1	−4	−7	−11	−19																
6	4	1	−1	−4	−7	−13	−21															
8	6	3	1	2	−5	−9	−14															
10	8	6	4	1	−2	−5	−9	−14	−18													
12	10	8	6	4	1	−2	−5	−9	−16													
14	12	11	9	6	4	1	−2	−5	−10	−17												
16	14	13	11	9	7	4	1	−1	−6	−10	−17											
18	16	15	13	11	9	7	4	2	−2	5	10	−19										
20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19									
22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19								
24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18							
26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9	−18						
28	27	25	24	22	27	19	17	16	14	11	9	7	4	1	−3	−9	16					
30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1	−2	−8	−15				
32	31	29	28	27	25	24	22	21	19	17	15	13	11	8	5	2	−2	−7	−14			
34	33	31	30	29	27	26	24	23	21	20	18	16	14	12	9	6	3	−1	−5	−12	−29	
36	35	33	32	31	29	28	27	25	24	22	20	19	17	15	13	10	7	4	0	−4	−10	
38	37	35	34	33	32	30	29	28	26	25	23	21	19	17	15	13	11	8	5	1	−3	9
40	39	37	36	35	34	32	31	30	28	27	25	24	22	20	18	16	14	12	9	6	2	−2

Dry-Bulb (Air) Temperature — Dew-Point Values

Activity 4 – Measuring dew-point temperature by condensation

Another way to determine the dew-point temperature is to cool a vessel until condensation begins to form on the outside of it. When you do this, it is very important that you change the temperature in small increments, and carefully monitor for the appearance of condensation. To get a feel for this activity, put about 100 mL of water into a 250 mL beaker. Dry the outside of the beaker. Measure the temperature with a digital thermometer. Put about 50 mL of ice into the water. Stir gently with the thermometer. Notice the drop in temperature. Touch the outside of the beaker to find out if there has been condensation. Now you realize how much the temperature drops with addition of ice, and how to feel condensation on the beaker.

Instructions to determine relative humidity by cooling air to the dew-point: Begin the measurement of the dew-point temperature by starting with a dry beaker at room temperature. Put about 150 mL of tap water into it. Add ice in 5 to 10 mL amounts, allowing it to completely melt before noting temperature and checking for condensation. You should add only enough ice each time to bring the temperature down about 1^{o} C. Continue until you notice condensation on the beaker. The temperature is your dew-point temperature. Record it below:

Dew-point temperature (°C) __________

Questions

18. Compare your measured dew-point temperature above with the value you determined using the psychrometer in Activity 3?

19. If the values are different, what factors might explain those differences?

Use Table 1 or Figure 1 to determine the values in questions 21 and 22.

20. What is the water vapor capacity of 50°F air? _________________
21. What is the water vapor capacity of 41°F air? _________________
22. If saturated air at 50°F is cooled to 41°F, how much water vapor will condense out of the air?

Part B – Adiabatic Processes

As you have seen in Part A, the key to causing water vapor to condense is to cool the air to its dew-point temperature. This is necessary before precipitation can occur. In nature, when air rises, it encounters less pressure, so it expands, and it cools. The reverse is also true. Air that descends encounters higher pressures, is compressed, and will warm. Temperature changes brought about solely by expansion or compression are called *adiabatic* temperature changes.

Air with a temperature above its dew point (unsaturated air) cools by expansion at a rate of **1 °C per 100 meters of changing altitude.** This is the **dry adiabatic lapse rate**. After the dew point temperature is reached, continued cooling cause condensation to occur. Latent heat that has been stored in the water vapor will be released. The heat being released by the condensing water slows down the rate of cooling of the air. Rising saturated air will continue to cool by expansion, but at a lesser rate of about **0.5 °C per 100 meters of changing altitude** – the **wet adiabatic lapse rate**. Descending air will always warm at the dry adiabatic lapse rate. This is because, as it warms, its water vapor capacity increases, and it is no longer saturated. (See Table 3 for demonstration of this effect.)

Figure 2 shows the movement of a parcel of air, starting at sea level with a temperature of 25ºC and a relative humidity of 50%. The air is forced to rise over a 5,000 meter mountain and descend to a plateau 2,000 meters above sea level on the opposite (leeward) side. Answer the questions on the following page. While doing so, think about the parallels between this problem and the orographic effect in western Oregon.

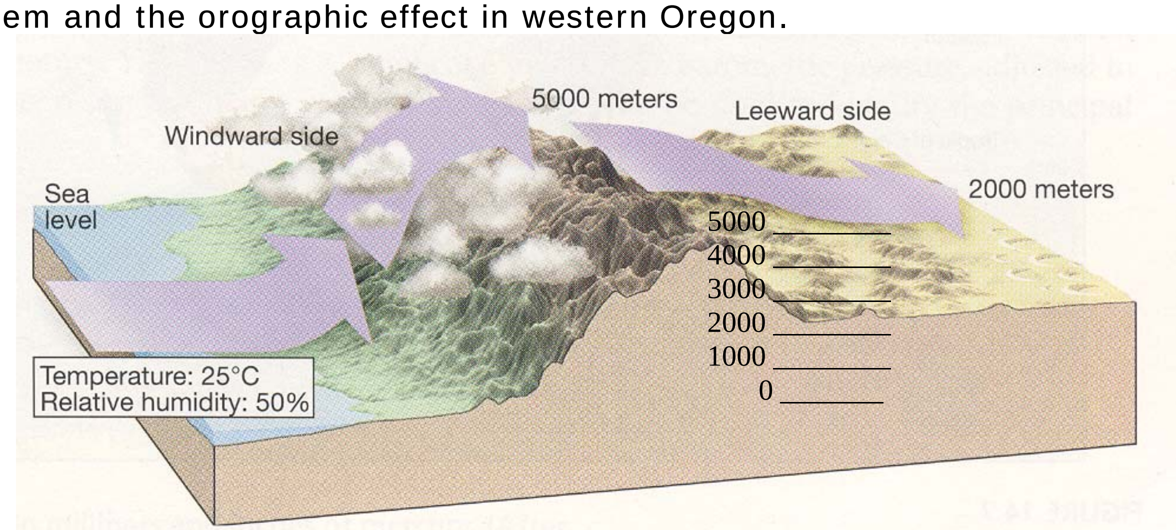

Figure 2: Adiabatic processes result in condensation associated with a mountain barrier.

In questions where you have to choose between more than response, CIRCLE YOUR ANSWER. Pay attention to your previous answers in later responses. You can write on the drawing on pg. 6.11 to keep track of the information. **See Table 1, 6 and 7** for specific values at certain temperatures.

Questions:

1. What is the water vapor capacity, content, and dew point temperature of the air at sea level? Capacity = ______________ g/kg of air

   Content = ______________ g/kg of air

   Dew-point temperature = ____________ ºC
2. The air at sea level is (**SATURATED** / **UNSATURATED**).
3. The air will initially (**WARM** / **COOL**) as it rises over the windward side of the mountain. It changes temperature at the (**WET** / **DRY**) adiabatic lapse rate, which is ______________ ºC per 100 meters.
4. What will be the air's temperature at 500 meters? __________________
5. Condensations (**WILL** / **WILL NOT**) take place at 500 meters. (See #1.)
6. The rising air will reach its dew point temperature at ________________ meters and water vapor will begin to (**CONDENSE** / **EVAPORATE**).
7. From the altitude where condensation begins to occur, to the summit of the mountain, the rising air will continue to expand and will (**WARM** / **COOL**) at the (**WET** / **DRY**) adiabatic lapse rate of about ______________ ºC per 100 meters.
8. The temperature of the rising air at the summit of the mountain (elevation 5000 meters) will be ______________ ºC.
9. What is the water vapor capacity when the air is at 5000 meters? ______
10. When the air begins to descend on the leeward side of the mountain, it will be compressed and its temperature will (**INCREASE** / **DECREASE**).
11. Assume that the relative humidity of the air is **below 100%** during its entire descent to the plateau. The air will be (**SATURATED** / **UNSATURATED**) and will warm at the (**WET** / **DRY**) adiabatic lapse rate of about ______________ ºC per 100 meters.
12. As the air descends and warms on the leeward side of the mountain, its relative humidity will (**INCREASE** / **DECREASE**).
13. The air's temperature when it reaches the plateau at 2,000 meters will be _____________ ºC.

Name________________________

Lab Day/Time_________________

POST-LAB ASSESSMENT

1. Explain why mountains might cause dry conditions on their leeward sides. (Recall page 6.12 to help you explain this phenomenon.)

Answer the following by circling the correct response.

2. Liquid water changes to water vapor by the process called (condensation, deposition, evaporation, sublimation).

3. (Warm, Cold) air has the greatest water vapor capacity.

4. Lowering the air temperature will (increase, decrease) the relative humidity.

5. At the dew-point temperature, the relative humidity is

6. (25%, 50%, 75%, 100%).

7. When condensation occurs, heat is (absorbed, released) by water vapor.

8. Rising air (warms, cools) by (expansion, compression).

9. In the early morning hours when the daily air temperature is often coolest, relative humidity is generally at its (lowest, highest).

10. Using the concepts that you have learned in today's lab, explain why when it is raining in the Willamette Valley, the weather is often sunny in Bend.

11. What is the dew-point temperature of a kilogram of air when a psychrometer measures an 8°C dry-bulb temperature and a 6°C wet-bulb reading?