ES 106 Laboratory # 6
MOISTURE IN THE ATMOSPHERE

Introduction

By observing, recording, and analyzing weather conditions, meteorologists attempt to define the principles that control the complex interactions that occur in the atmosphere. No analysis of the atmosphere is complete without an investigation of water vapor in atmosphere, which strongly influences humidity and precipitation. 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). 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.

Weather plays an important role in our daily lives. We want to know what the weather is going to be like 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. The second part of this laboratory focuses on making weather observations.

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.

Name_____**KEY**_______________

Lab Day/Time_________________

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

1. Define the following terms:
   A. Relative Humidity **AMOUNT OF WATER CONTAINED IN AIR COMPARED TO HOW MUCH WATER THE AIR COULD HOLD.**

   B. Dew-point temperature **THE TEMPERATURE AT WHICH CONDENSATION BEGINS, WHEN THE AIR IS AT 100% RELATIVE HUMIDITY.**

   C. Adiabatic temperature change **THE CHANGE IN TEMPERATURE DUE TO THE EXPANSION (LOWERING THE TEMPERATURE) OR COMPRESSION (RAISING THE TEMPERATURE) OF AIR.**

   D. Condensation **THE PROCESS OF CHANGING WATER VAPOR INTO LIQUID WATER. CONDENSATION OF WATER RELEASES HEAT TO THE ENVIRONMENT.**

2. Explain why the dry adiabatic lapse rate is greater than the wet adiabatic lapse rate.
   THE COOLING OF AIR AT THE DRY RATE IS GREATER THAN WHEN THE AIR HAS REACHED 100% RELATIVE HUMIDITY, AND COOLS AT THE WET RATE, BECAUSE THE CONDENSATION OF WATER RELEASES HEAT TO THE ENVIRONMENT.

3. If a beaker has the capacity to hold 600 mL of liquid and the beaker is 40% full, calculate the volume of liquid in the beaker. (Show formula for calculation, with units.)
   600 mL x 0.4 = 240 mL

4. If a beaker has the capacity to hold 800 mL of liquid and it is currently holding 150 mL, calculate the percentage of the beaker that is filled. (Show formula for calculation, with units.)
   (150 mL / 800 mL) x 100 = 18.75%

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 limited by, and directly related to, 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 (ºF)	**Temperature (ºC)**	**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 water vapor capacity and air temperature, prepare a graph by plotting the data from Table 1 in Figure 1.

2. What is the water vapor capacity of a kilogram of air at each of the following temperatures?

40º C: ________**47**_______________ grams/kilogram

68º F: ________**14**_______________ grams/kilogram

0º C: _________**3.5**_______________ grams/kilogram

-20º C: _________**0.75**_______________ grams/kilogram

3. Raising the air temperature of a kilogram of air 5 degrees C, from 10 to 15 degrees C, (**INCREASES** / DECREASES) its water vapor capacity by (**3** / 6) grams. However, raising the temperature from 35 to 40 degrees C (**INCREASES** / DECREASES) the capacity by (8 **/ 12**) grams. (CIRCLE YOUR ANSWERS)

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

THE GREATER THE TEMPERATURE, THE MORE WATER THE AIR CAN HOLD.

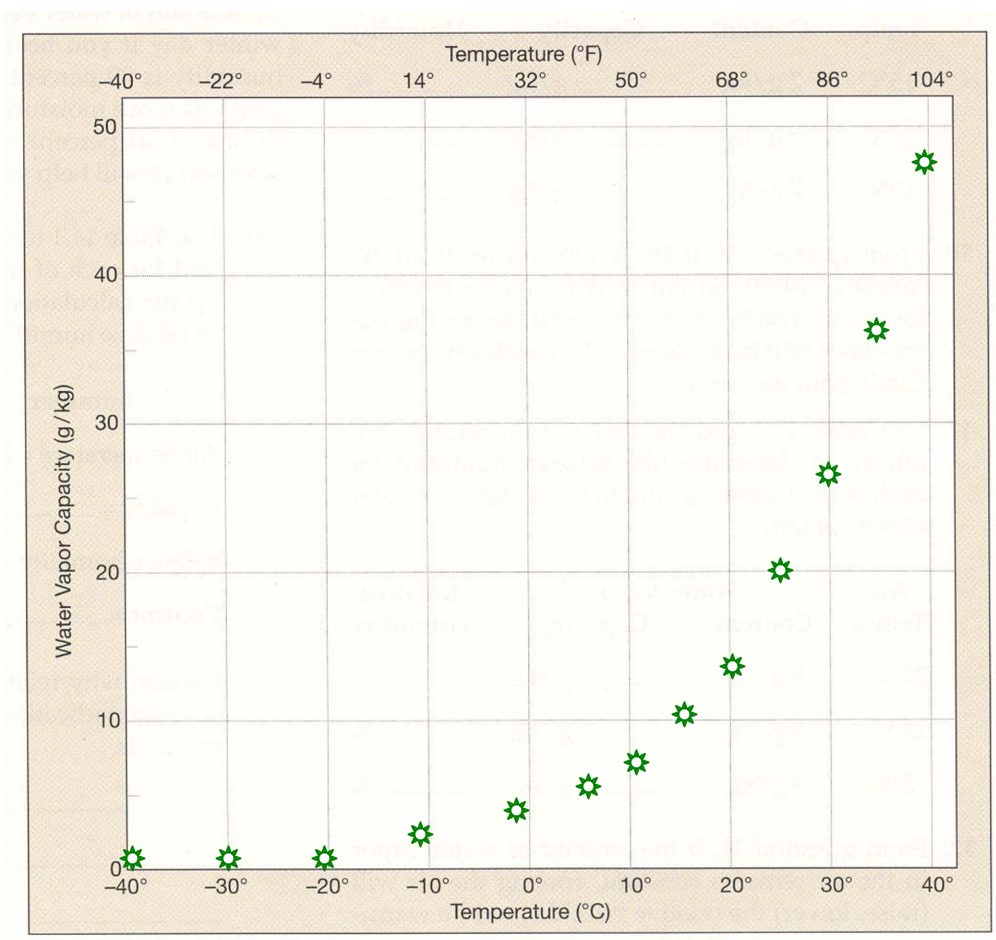

Figure 1: Graph of water vapor capacity of a kilogram of air versus temperature. Refer to Table 1 for values.

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:

Relative humidity (%) = (water vapor content / water vapor capacity) 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 and the formula above for relative humidity to determine the relative humidity for each of the following situations of identical temperature.

Air Temp (in ºC)	Water Vapor Content	Water Vapor Capacity	Relative Humidity
15ºC	2 g/kg	**10** g/kg	**20** %
15ºC	5 g/kg	**10** g/kg	**50** %
15ºC	7 g/kg	**10** g/kg	**70** %

6. From the previous question, if the temperature of air remains constant, adding water vapor will (**RAISE** / LOWER) the relative humidity, while removing water vapor will (RAISE / **LOWER**) the relative humidity. (CIRCLE YOUR ANSWERS)

7. Use the Table 1 and the formula above for relative humidity to determine the relative humidity for each of the following situations of identical water vapor content.

Air Temp (in ºC)	Water Vapor Content	Water Vapor Capacity	Relative Humidity
25ºC	5 g/kg	**20** g/kg	**25**%
15ºC	5 g/kg	**10** g/kg	**50** %
5ºC	5 g/kg	**5** g/kg	**100** %

8. From the previous question, if the amount of water vapor in the air remains constant, cooling the air will (**RAISE** / LOWER) the relative humidity, while warming the air will (RAISE / **LOWER**) the relative humidity. (CIRCLE YOUR ANSWERS)

9. 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?
THE AIR BROUGHT IN FROM OUTSIDE HAS A LOW WATER CONTENT. AS IT IS HEATED, THE RELATIVE HUMIDITY IS REDUCED. IF YOU DO NOT LIKE LOW-HUMIDITY AIR, MOVE INTO A GREENHOUSE WITH LOTS OF TRANSPIRING PLANTS, OR GO TO BI-MART AND GET A HUMIDIFIER.

10. Explain why a cool basement is humid (damp) in the summer.
THE WARM AIR FROM OUTSIDE HAS A CERTAIN WATER CONTENT. WHEN IT IS COOLED IN THE BASEMENT, THE RELATIVE HUMIDITY INCREASES, SOMETIMES TO 100% RELATIVE HUMIDITY, CAUSING THE BASEMENT AIR TO BE DAMP

11. Write brief statements describing each of the two ways that the relative humidity of air can be changed.
CHANGE THE MOISTURE CONTENT OF THE AIR.
CHANGE THE TEMPERATURE OF THE AIR.

One of the misconceptions 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? The next several questions will address this question.

12. 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.

SUMMER	**WINTER**
Air temperature = 86ºF	Air temperature = 50ºF
Capacity = ___**26.5**_______ g/kg	Capacity = ____**7**______ g/kg
Relative humidity = 20%	Relative humidity = 76%
Content = ___**5.3**_______ g/kg	Content = _____**5.32**_____ g/kg

13. Explain why relative humidity does not give an accurate indication of the amount of water vapor in the air.

BECAUSE IT RELATED TO HOW MUCH WATER THE AIR CAN CONTAIN.

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% and was 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.

14. By referring to Table 1, what is the dew-point temperature of a kilogram of air that contains 7 grams of water vapor?

Dew-point temperature = ________**10**_____________ ºC

15. What is the relative humidity and dew-point temperature of a kilogram of 25ºC air that contains 10 grams of water vapor?

Relative humidity = _________**50**_____________ %

Dew-point temperature = _____**15**_________________ ºC

Activity 3 – Measuring humidity using a psychrometer

A psychrometer measures humidity by measuring the difference in temperature between a thermometer with a dry bulb and a thermometer with its bulb inside a wet cloth. As the two thermometers are slung through the air, air rushing over the wet cloth cools the wet-bulb thermometer more than the dry-bulb thermometer. A table can be used to convert the temperature difference into a relative humidity measurement.

Relative Humidity Values

Dry-bulb (Air) Temperature

Dry-bulb Tempera-ture (°C)	*Depression of Wet-bulb Temperature* (Dry-bulb Temperature − 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	43	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	33	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	71	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	0								
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	47	42	36	31	26	21	17	12	8	2					
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

*To determine the relative humidity and dew point, 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 or dew point is found. For example, use a dry-bulb temperature of 20°C and a wet-bulb temperature of 14°C. From Table 14.2, the relative humidity is 51 percent, and from Table 14.3, the dew point is 10°C.

Table 2: Relative Humidity determined by Wet Bulb Temperature Depression

Following the instructions given by your lab instructor, record the temperatures of the wet- and dry-bulb thermometers on the psychrometer in the table below. Calculate the relative humidity and the dewpoint temperature.

Dry-bulb temperature (°C)	**26 ^{O} C**
Wet-bulb temperature (°C)	**21 ^{O} C**
Difference between dry- and wet-bulb temperatures (°C)	**5 ^{O} C**
Relative humidity	**64%**
Dew-point temperature	**18^{O} C**

Activity 4 – Measuring dew-point temperature

Add ice gradually to a container of water while gently stirring the ice water with a thermometer. Note the temperature at which condensation first appears on the outside of the container. This is the dew-point temperature. Record your value for the dew-point temperature in the space below.

Dew-point temperature (°C) _**18 ^{O} C** _________

Questions

1. How does your measured dew-point temperature compare with the value you determined in Activity 3 using the psychrometer? If the values are different, what factors might explain those differences?
   DIFFERENCES MAY EXIST DUE TO NOT ALLOWING THE SLING PSYCHRMETER WET BULB TO GAIN COMPLETE DEPRESSION OF TEMPERATURES (NOT SLUNG FOR LONG ENOUGH), OR PERHAPS THE CONDENSATION ON THE BEAKER WAS NOT NOTED AS SOON AS IT APPEARED, OR THE ICE WAS NOT ALLOWED TO COMPLETELY MELT BEFORE ADDING MORE, OR TOO MUCH WAS ADDED AT ONE TIME, RESULTING IN A LOWER TEMPERATURE BEING INDICATED THAN THAT WHERE CONDENSATION BEGAN.
2. How many grams of water vapor will condense out of the air if a kilogram of 50°F air with a relative humidity of 100% is cooled to 41°F?
   50^{O} F = 7 g
   41^{O} F = 5 g
   2 g WOULD CONDENSE OUT OF AIR THAT IS COOLED FROM 50 ^{O} F TO 41 ^{O} F

Part B – Adiabatic Processes

As you have seen, the key to causing water vapor to condense, which is necessary before precipitation can occur, is to cool the air to its dew-point temperature. In nature, when air rises, it encounters less pressure, expands, and 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 or warms by compression at a rate of **1 °C per 100 meters of changing altitude** – the **dry adiabatic lapse rate**. After the dew point temperature is reached, and as condensation occurs, 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**.

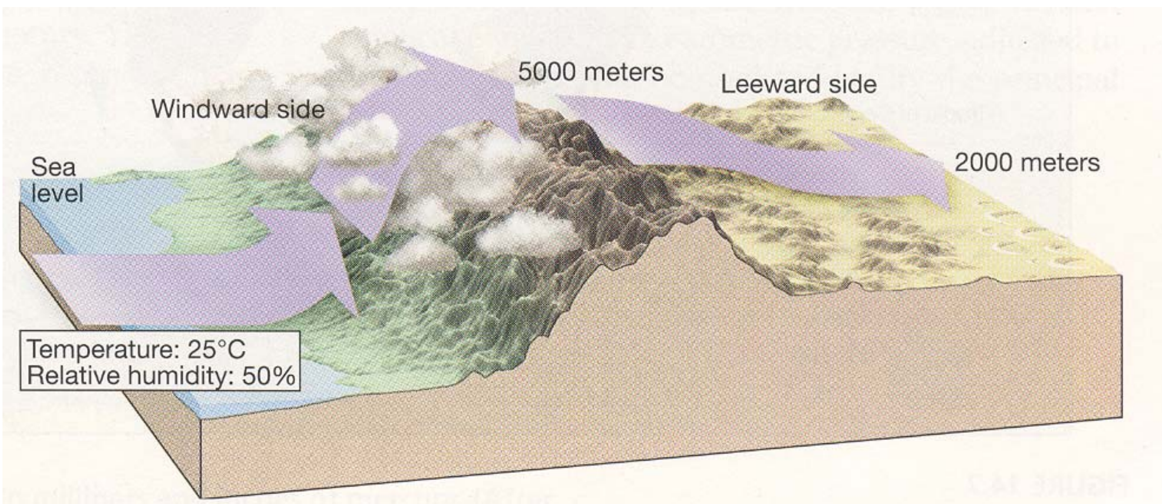

Figure 2: Adiabatic processes result in condensation associated with a mountain barrier.

Figure 2 shows a kilogram of air at sea level with a temperature of 25ºC and a relative humidity of 50%. The air is forces 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. In questions where you have to choose between more than response, CIRCLE YOU ANSWER.

Questions:

1. What is the water vapor capacity, content, and dew point temperature of the air at sea level?

   Capacity = ________**20**________________ g/kg of air

   Content = __________**10**________________ g/kg of air

   Dew-point temperature = _____________**15**___________ 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 at the (WET **/ DRY**) adiabatic lapse rate, which is _____**1**_________ ºC per 100 meters.

   #4. 500 m x 1 ^{O} C/100 m = 5 ^{O} C 25 ^{O} C –5 ^{O} C =
4. What will be the air's temperature at 500 meters? _______**20 ^{O} C**___________________

5. Condensations (WILL **/ WILL NOT**) take place at 500 meters.

   #6 25 ^{O} C –15 ^{O} C = 10 ^{O} C 10 ^{O} C / (1 ^{O} C/100 m) =
6. The rising air will reach its dew point temperature at ____**1000**_____________ 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 ______**0.5**________ ºC per 100 meters.

   #8: 5000 m –1000 m = 4000 m 4000 m x 0.5 ^{O} C/100 m = 20 ^{O} C 15 ^{O} C –20 ^{O} C =
8. The temperature of the rising air at the summit of the mountain will be _____**—5** ______ ºC.

9. Assuming that the air begins to descend on the leeward side of the mountain, it will be compressed and its temperature will **(INCREASE** / DECREASE).

10. 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 _____**1**__________ ºC per 100 meters.
11. As the air descends and warms on the leeward side of the mountain, its relative humidity will (INCREASE / **DECREASE**).
12. The air's temperature when it reaches the plateau at 2,000 meters will be ___**25**_______ ºC.
13. Explain why mountains might cause dry conditions on their leeward sides.

    AIR LOSES MOISTURE AS IT COOLS. THE TEMPERATURE INCREASES AS IT DESCENDS THE LEE SIDE AT THE DRY RATE, AND THE MOISTURE CONTENT AND RELATIVE HUMIDITY IS LESS THAN THE ORIGINAL COASTAL AIR.

Name______**KEY**___________

Lab Day/Time_________________

POST-LAB ASSESSMENT

1. Answer the following by circling the correct response.

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

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

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

   D. At the dew-point temperature, the relative humidity is (25%, 50%, 75%, **100%**).

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

   F. Rising air (warms, **cools**) by (**expansion**, compression).

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

2. Explain the principle that governs the operation of a psychrometer for determining relative humidity.
   THE WETTED SOCK COOLS THE TEMPERATURE BY EVAPORATION REMOVING THE HEAT, REDUCING THE TEMPERATURE. THE EVAPORATION CONTINUES UNTIL NO MORE WATER CAN EVAPORATE DUE THE HUMIDITY OF THE AIR. THE TEMPERATURE STOPS DROPPING AT THAT POINT, AND THE DEPRESSION OF TEMPERATURE CAN BE COMPARED TO TABLES TO FIND THE RELATIVE HUMIDITY OF THE AIR.

3. 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
   THE AIR RAINS BECAUSE IT IS LIFTED BY RUNNING INTO THE CASCADE RANGE AND COOLED. AS IT COOLS, ITS MOISTURE CONTENT IS REDUCED, AND IT RAINS. AS IT DESCENDS THE CASCADE RANGE ON THE BEND SIDE, IT IS LESS THAN 100% RELATIVE HUMIDITY, DRY AND CLEAR.

4. 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.
   2^{O} C DEPRESSION, READ OFF CHART ON PAGE 687 IN *EARTH SCIENCE* TEXTBOOK: DEW POINT TEMPERATURE IS 3^{O} C