Adiabatic Temperature and Clouds

Atmospheric Science

Introduction

You have all heard the phrase “heat rises.”

In this set of activities, you will be investigating how air pressure affects the temperature of air and how this relates to the formation of clouds in the troposphere. You will form a cloud in a bottle (hopefully), find the dewpoint and relative humidity of air, use a chart to estimate how high that would have to rise to form a cloud.

Part 1: Relationship Between Pressure and Temperature

In order to explore how clouds form in the atmosphere, we have to examine the relationship between changes in air pressure and temperature. As air rises in the atmosphere, the air pressure decreases. This is because there is less air (atmosphere) above it pushing down. With less atmosphere (air molecules), the air expands. You will be adding air to a two liter soda bottle and examine what happens to the mass and temperature of the air inside the bottle.

Materials: digital scale, empty 2 liter bottle, fizz keeper pressure pump, thermometer, smoke from match

Part 1: Procedure

1. Attach a pressure pump to a two-liter bottle.

2. Measure the mass of the bottle and record the temperature.

3. Pump 30 times. Record the mass and temperature. Repeat for 60, 90, 120, 150, 180, and 210 pumps.

4. Release the pressure and record the mass and temperature.

Part 1: Data Analysis

1. Open a Google Sheet.

2. In Column A, enter the Number of Pumps/Increasing Pressure.

3. In Column B, enter the Mass.

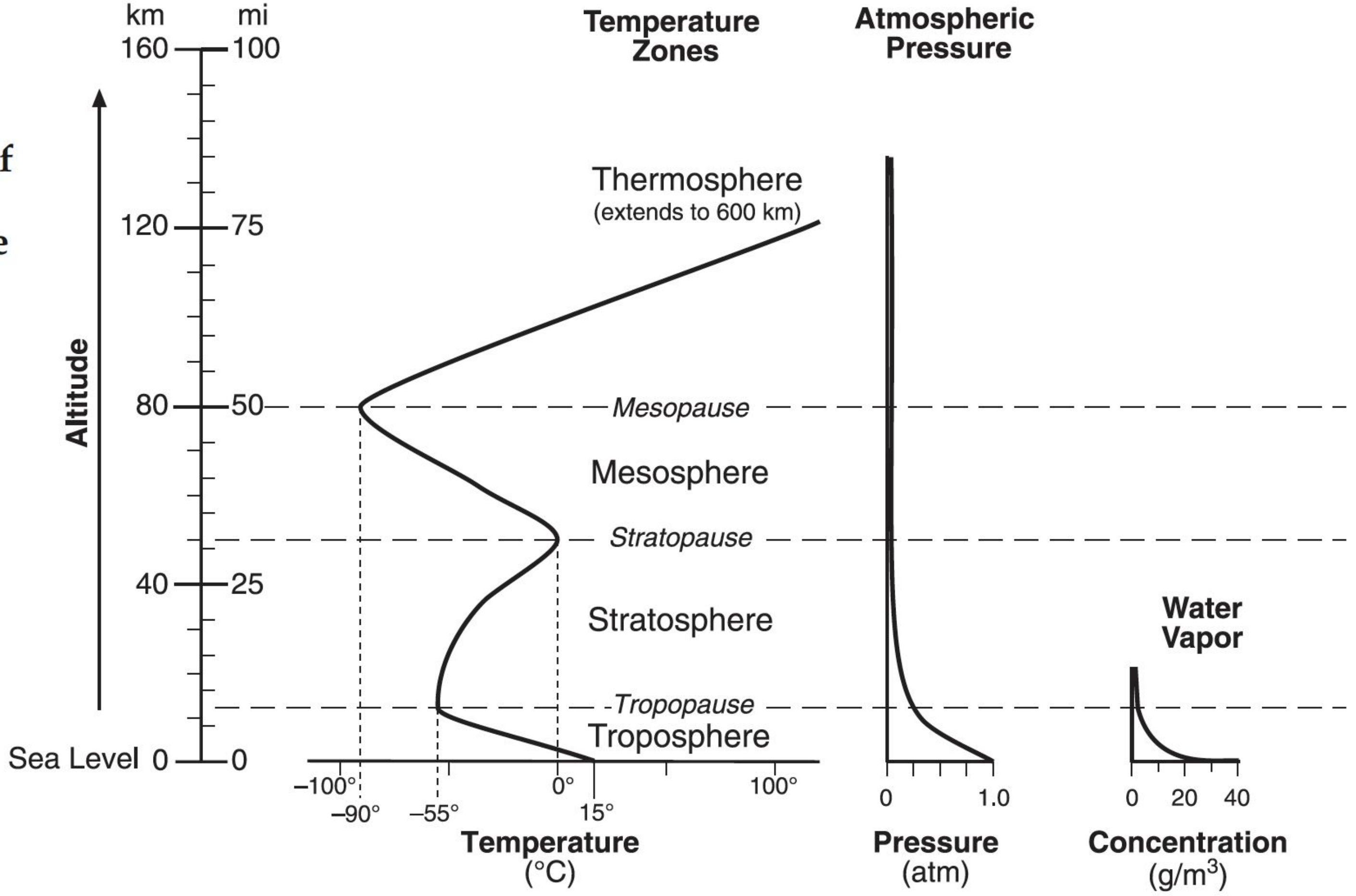
4. Create a graph. Title your graph: “The Effect of Pressure Changes on Mass.” Insert your graph on a new slide.

5. Create a second graph, “The Effect of Pressure Changes on Temperature.” Insert your graph on a new slide.

Part 1: Analysis

1.. When the 2 L bottle was being pumped, did the air in the bottle expand or contract? What did the temperature do in response to the bottle being pumped?
2. When the bottle was opened, did the air pressure increase or decrease?   What did the temperature do in response to the bottle being opened?
3. According to the ESRT, what happens to the air pressure when you increase the altitude in the troposphere?
4. According to the ESRT, what happens to the temperature when you increase the altitude in the troposphere?
5. Look at the graph of water vapor concentration with respect to altitude on the ESRT. What implications does this graph have for cloud formation?
6. As air rises in the atmosphere, does the air expand or contract?
7. When air expands, does the temperature increase or decrease?

Selected Properties of Earth's Atmosphere



Part 2: Cloud Formation

1. Pressurize the two liter bottle by pumping it 100 times.

2. Release the pressure. Do you see a cloud?

3. Slip in a lit match so that you create smoke in the bottle.

4. Re-pressurize your bottle 100 times.

5. Release the pressure. Do you see a cloud?

Part 2: Analysis Questions

1. Under what conditions did you see a cloud form? Increased pressure or decreased pressure?

2. A cloud condensation nuclei is a surface on which water vapor may condense, thus beginning the cloud formation process. For this activity/demo, what substance serves as the cloud condensation nuclei?

3. Are clouds composed of water vapor? Why or why not?

Part 3: Cloud Base Altitude

As air rises, there is less atmosphere above it so there is less pressure on it and the air molecules can spread out or expand. As they spread out, they "take their heat with them." The expansion of air causes the temperature to drop, though no heat is actually taken from the air. Temperature changes that occur due to expansion or contraction and without the gain or loss of heat are called **adiabatic** temperature changes. Normally as air rises in the lower atmosphere, the temperature drops at a rate of 10 C for each kilometer it rises, as long as the air is unsaturated. This is known as the dry adiabatic lapse rate.

When the air is saturated, the temperature drops at a rate of about 6 C for each kilometer it rises. This is known as the wet adiabatic lapse rate.

Part 3: Cloud Base Altitude

When the air spreads out (as it rises), it opens up space which more water vapor molecules can fill. This allows more water molecules to evaporate into the air than would have at a lower altitude. This lowers the dew point by a rate of about 2 C for each kilometer rise. This is known as the dew point lapse rate.

When air is cooled below its dew point, “condensation exceeds evaporation” and the amount of liquid water increases as cloud/fog droplets form and grow. As air rises, the temperature drops 10 C per kilometer and the dew point drops 2 C for each kilometer. If this goes on long enough, the falling temperatures will eventually catch up to the falling dew point. When this happens, condensation will exceed evaporation and tiny droplets of liquid water will form in the air. This point is called the lifting condensation level.

Source: Slides 1 - 10 Adiabatic Temperature and Clouds

Part 3: Procedure I

1. Using a sling psychrometer, determine the dry bulb temperature and the wet bulb temperature.

2. Using the data table to determine the dew point.

3. Use the lapse rate table to find where the temperature line and the dewpoint line intersect.

4. Use this information to determine the “theoretical” cloud base altitude.

Part 3: Data Table, Part 1

Dry Bulb Temperature (C)	
Wet Bulb Temperature (C)	
Dewpoint (C)	
Cloud Height (km)	

Source: Slides 11-12 Earth Science Investigations 2nd Edition by Sanders, Topical Review

Part 3: Procedure II

We will use the Pocket Lab Air for this part of the data collection.

1. Connect the Pocket Lab Air to your mobile device. You may also use a Vernier temperature probe and relative humidity probe.

2. At your recording location, determine the air temperature and relative humidity.

3. Use the dew point calculator to determine the dew point.

4. Use this information to determine the “theoretical” cloud base altitude.

Part 3: Data Table, Part 2

Air Temperature (C)	
Relative Humidity (%)	
Dewpoint (C)	
Cloud Height (km)	

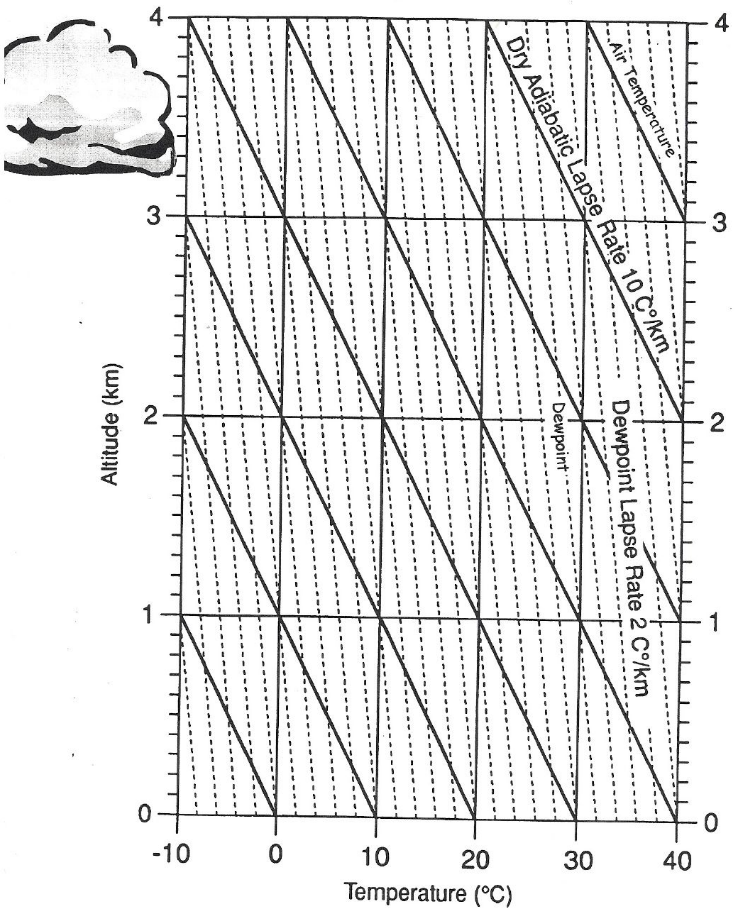
Dewpoint (°C)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
−20	−20	−33														
−18	−18	−28														
−16	−16	−24														
−14	−14	−21	−36													
−12	−12	−18	−28													
−10	−10	−14	−22													
−8	−8	−12	−18	−29												
−6	−6	−10	−14	−22												
−4	−4	−7	−12	−17	−29											
−2	−2	−5	−8	−13	−20											
0	0	−3	−6	−9	−15	−24										
2	2	−1	−3	−6	−11	−17										
4	4	1	−1	−4	−7	−11	−19									
6	6	4	1	−1	−4	−7	−13	−21								
8	8	6	3	1	−2	−5	−9	−14								
10	10	8	6	4	1	−2	−5	−9	−14	−28						
12	12	10	8	6	4	1	−2	−5	−9	−16						
14	14	12	11	9	6	4	1	−2	−5	−10	−17					
16	16	14	13	11	9	7	4	1	−1	−6	−10	−17				
18	18	16	15	13	11	9	7	4	2	−2	−5	−10	−19			
20	20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19		
22	22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19	
24	24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18
26	26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9
28	28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	−3
30	30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1

Relative Humidity (%)

Dry-Bulb Tempera-ture (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
−20	100	28														
−18	100	40														
−16	100	48														
−14	100	55	11													
−12	100	61	23													
−10	100	66	33													
−8	100	71	41	13												
−6	100	73	48	20												
−4	100	77	54	32	11											
−2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

CLOUD BASE ALTITUDE CHART - Cumulus clouds



Part 3: Questions

1. Why would the height of a cumulus cloud base change from day to day?

2. What would happen to the height of the cloud base if the dew point were lower?

3. How should the air temperature of a descending air mass change?

4. How should the dew point temperature of a descending air mass change?

5. Explain why a descending mass of air should tend to be drier.