METR 104:
Our Dynamic Weather
(Lecture w/Lab)

Some Demonstration Experiments: Effects of Air Motion, Evaporation, and Pressure Changes on Temperature

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Objectives. During and after these demonstration experiments, students should be able to:

- observe and record results of several experiments about changes in temperature measured by a thermometer
- propose and/or evaluate possible explanations for some of the observations, reasoning from prior knowledge and evidence from the experiments

Background Knowledge:

- conduction
- how most thermometers work
- wind chill
- evaporation vs. condensation (two phase changes of water)
- adiabatic cooling and warming

Materials Needed. To complete this exploration,we will need:

- for the wind chill experiment:
    - several thermometers (liquid-in-glass and/or thermocouples)
    - an electric fan
    - some water
- for the bicycle tire experiment:
    - a bicycle tire
    - tire pump
    - a thermometer (liquid-in-glass and/or thermocouple)

I. Introduction.

In these demonstration experiments, we'll explore how air motion (wind), evaporation, and pressure changes affect (or don't affect) temperature as measured by a thermometer.

II. Instructions. For each of the demonstration experiments described below, *observe and carefully record what you see, including both qualitative (descriptive) results and quantitative results (measurements)*. For some things, your instructor will ask for help.

Later (out of class, via iLearn) you'll be asked to refer to some of your observations (as well as Reading #6 and Lab Exploration #8) to support or disconfirm possible explanations for what you see happening. Hence, you need to record detailed and accurate notes of what you observe, for later reference.

A. **Wind chill experiment: wind and temperature**

   You need to know:
   - how a thermometer works (via conduction between the thermometer sensor and the air in contact with it)
   - how to read a thermocouple output plot or a liquid-in-glass thermometer

   The experimental setup: an electric fan, with several thermometers mounted in front of it and behind it.

   1. The fan is initially turned off. Read the thermometers and record their temperatures.

   2. Predict what will happen to the temperatures measured by the thermometers after the fan is turned on.

   3. Turn the fan on "low" and wait a minute.

   4. Reread the thermometers and record their temperatures.

   5. Turn the fan on "high" and wait a minute.

6. Reread the thermometers and record their temperatures.

7. Compare your prediction to what you observed and discuss what might be going on.

8. Predict what will happen to the temperatures measured by the thermometers after dipping them in water and holding them in front of the fan.

9. Dip the thermometers in some water, hold them in front of the fan, and record what happens to the temperatures.

10. Compare your predictions to what you observed and discuss what might be going on.

B. **Bike tire experiment: pressure and temperature**

You need to know:

- a typical atmospheric pressure (in pounds per square inch) at the altitude of the classroom (which in our case is close to sea level)
- the maximum recommended pressure (in pounds per square inch) inside an inflated bike tire (printed on the side of the tire)
- how to open the valve on a bike tube (a shrader-type valve or a presta-type valve)
- how to use a hand pump to pump air into the bike tube

The experimental setup: an inflated bike tire, several thermometers, and a bike pump

1. With a thermometer, measure and record the air temperature in the room.

2. We can't easily measure the temperature of the air inside the bike tire, but given that (a) the bike tire has been sitting around in the room for a while, (b) the air temperature in the room hasn't been changing much, and (c) knowing how conduction works, what would you say about the temperature of the air inside the tire compared to the room temperature (higher, about the same, or lower)? Why?

3. Answer the same question about the valve on the bike tube.

4. With your fingers, briefly feel the metal part of the valve on the bike tube. Does it feel warm, neutral, or cool?

Why, do you think? [Note: when something feels warm or cold, what you're actually feeling is your own skin temperature, because that's where the nerves are that are responsible for detecting and signaling temperature change. Similarly, a thermometer really only measures its own temperature. If your skin is warmer than it's "normal" temperature (around 91°F), your skin will feel warm or hot. When it cooler than "normal", it will feel cool or cold. If you touch an object and "it" feels warm or cold, that means that your skin has gained or lost heat (probably by conduction of heat from or to the object respectively, which will happen if the object is warmer or cooler than your skin, respectively).

5. Given the pressure exerted by the air inside the tire and the pressure of the air in the room outside the tire, what should the air inside the tire do when the valve is opened? Why? (What physical principle that we've learned about applies here?)

6. Position the sensor of a thermometer directly in front of the tire valve, so you can measure the temperature of the air immediately after it leaves the tire. For a schrader-type valve, using the tip of a ball-point pen or other narrow, pointy object, open the valve and let air out of the tire until it stops coming out, measuring its temperature the whole time. For a presta-type valve, unscrew the valve closure and press down on the pin sticking out of the valve. Record the temperature at the point when it has changed the most.

7. Quickly and briefly feel the metal part of the valve again with your fingers. Does it feel warmer, no different, or cooler than it did before the air escaped? Why, do you think? (That is, if it changed temperature, by what mechanism did it gain or lose heat?)

8. Compare the temperature of the air after it escaped from the tire to the temperature you think the air inside the tire had before the air escaped. If the temperature differs, think about the mechanism(s) by which it might have gained or lost heat to account for the temperature change. In particular, what candidate mechanisms seem possible in this case, at least in principle? Which one(s) is (are) seem the most likely to have acted here?

9. Using the tire pump, pump air back into the tire. Feel the valve again. Has its temperature changed? If so, how do you think it happened?

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Lab Exploration #8: Moisture, and Cloud Formation

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(*Lab Section 1:* Wed., May 15; *Lab Section 2:* Fri., May 17)

Objectives. During and after this lab exploration, students should be able to:

- observe and record results of several experiments relevant to cloud formation involving air temperature, air pressure, and moisture
- propose and/or evaluate possible explanations for some of the observations, reasoning from prior knowledge and evidence from the experiments

Background Knowledge:

- conduction
- how a thermometer works
- wind chill
- evaporation vs. condensation (two phase changes of water)
- water vapor content of air vs. water vapor capacity of air
- saturation (of air with water vapor)
- relative humidity
- dew point temperature
- using a sling psychrometer to record dry bulb and wet bulb temperature
- determining dew point and relative humidity from dry bulb and wet bulb temperature
- adiabatic cooling and warming
- aerosols
- what a cloud consists of

Materials Needed. To complete this exploration, you will need:

- for the dew point and relative humidity measurement:
  - sling psychrometer

    - dew point and relative humidity tables

- for the pressure-, temperature-, and moisture-in-a-bottle experiments:
    - a one-gallon, narrow-necked glass bottle
    - rubber stopper, rubber hose, and vacuum bulb
    - small amount of water at room temperature
    - wooden matches
    - a thermocouple thermometer
    - a flashlight
    - digital scale with 0.1 gram precision

I. Introduction.

Water vapor is water (H_2O) in the form of a gas. It is an invisible and odorless, and there is always at least a little bit present in the air.

In contrast, when clouds are present they are quite visible. A cloud consists of a large collection (aggregate) of tiny water droplets and/or ice crystals, (virtually) suspended in the air. Cloud droplets and cloud ice crystals are individually too small to see but collectively they scatter enough visible light for us to see the aggregate.

Clouds reflect sunlight back to space, contribute to the greenhouse effect, and exhibit a wide range of forms, extent, and altitude. They tell something about the state and motion of the atmosphere, and can inspire in us feelings ranging from awe to delight to fear to melancholy. Some (though not most) clouds are capable of producing precipitation.

In this lab, you'll explore some of the conditions and mechanisms that can lead to the creation of most kinds of clouds in the atmosphere.

II. Instructions. Your instructor will assign you to a group of 3-4 people. Your group will perform the experiments described below.

For each of the experiments, *observe and carefully record what you see, including both qualitative (descriptive) results and quantitative results (measurements)*. For some things your instructor will assign tasks, while for other things you'll assign tasks to yourselves within your group. In some cases you'll carry out the experiment or parts of it, while in other cases you'll be observing and recording results.

Before you carry out each experiment, *read all of its instructions* so you know what sequence of actions you're about to take, and decide in advance exactly who will be doing what and that each person understands how to perform their assigned task(s).

Although you won't turn in anything at the end of this lab, later (out of class, via iLearn) you'll be asked to refer to some of your observations from this lab and from demonstrations performed in lecture (plus information in Reading #6) to confirm (support) or disconfirm possible explanations for what you see happening. Hence, *you need to record detailed and accurate notes of what you observe, for later referenc*e.

A. **Temperature and pressure inside of a bottle.**

You need to know:
- how to read a thermocouple (electronic thermometer) graph
- how to pump air into a bottle using a vacuum bulb
- how to read a digital scale and set it to read zero (weight) with an object on the scale

The experimental setup: a one-gallon, narrow-necked glass bottle; a rubber stopper and a vacuum bulb, connected by a flexible rubber or plastic tube; a thermocouple threaded through a hole in the stopper with the sensor inside the bottle; a cup with a little water in it; and a digital scale.

- Does air have weight?

1. Make sure that the rubber stopper is inserted firmly into the mouth of the bottle, so it is air tight. (Moistening the stopper slightly first can improve the seal.)

2. Make sure the digital scale is plugged in and turned on. Set it so that it records in grams (not ounces). Place the bottle on the digital scale. Hold the rubber tube firmly against the table or countertop surface so that the portion of the tube between the stopper and the point where you're holding it won't move (but not so firmly that you pinch the tube closed).

3. "Zero" the weight scale (press the "tare" or "Z" button) to get it as close to zero as you can. When the weight reading is stable, record it.

4. Using the vacuum bulb, pump as much air into the bottle as you can, while one person continues to hold the rubber tube firmly against the table or countertop and another person prepares to prevent the stopper from flying too far should it pop off.

   Everyone not directly involved should step back, and those directly involved should use an arm or hand to shield their face against a flying object. If the person pumping gets tired, someone else should take over. [Does the difficulty of pumping change as you pump air into the bottle? Think about why or why not.] Continue to note the weight indicated by the scale. Record the weight at the point where it differs the most from the starting weight (assuming that the rubber tube between the bottle and the point where you're holding against the table or countertop hasn't moved).

- How does changing pressure affect temperature in a bottle?

  1. Plug the thermocouple into the USB port of one of our Mac laptops, and start the Logger Lite software (green notebook icon on the "Dock"). Insert the stopper firmly into the bottle, with the thermocouple sensor inside.

  2. On the laptop, click on the big, green "Collect" button at the top of the Logger Lite window. When the temperature inside the bottle is relatively steady, record it.

3. While one person holds the rubber stopper firmly in place, a second person should shine a flashlight through the bottle from the side. While the stopper continues to be held firmly in place to prevent air from leaking (and the stopper from popping off), a third person should use the vacuum bulb to pump air into the bottle until they can't pump any more in.

4. Carefully loosen the stopper until it pops off, but hold it loosely (a) to prevent it from flying away and hitting someone, and (b) to keep the thermocouple sensor inside the bottle. Immediately reinsert the stopper afterwards. If you see that anything inside the bottle has changed, record the observation.

5. After a short time (less than 30 seconds), click on the big, red button at the top of the Logger Lite window to halt plotting of the temperature. To adjust the vertical scale on the temperature plot and make it easier to read, click on the "Scale" icon on the tool bar along the top of the Logger Lite window. (The Scale icon has a big blue "A".) Record the change in temperature, if any, that occurred between the time just before you opened the stopper and just after you popped it off. (If there was a change, think about what might have caused it.)

6. Loosen the stopper and pump some air into the bottle to flush out the air inside and replace it with new air. When the temperature inside returns to the value roughly where it started in Step (1) above, remove the stopper and the thermocouple sensor, tip the bottle a little, and pour in just enough water to cover the bottom of the bottle. Set the bottle upright, insert the thermocouple sensor and firmly insert the stopper. (You'll come back to the bottle later.)

B. **Measuring dew point temperature and relative humidity**

You need to know:

- how a sling psychrometer works and how to use it to measure dry bulb and wet bulb temperatures
- how look up the dew point temperature and relative humidity in a table, given the dry bulb and wet bulb temperatures

The setup: a sling psychrometer, with the cloth sack over the bulb of one of the thermometers moistened with water.

1. Note the temperatures recorded by the wet bulb and the dry bulb on the sling psychrometer. (Are they different? If so, why do you think so, given that the water used to moisten the wet bulb had essentially the same temperature as the air in the room?)

2. If you were to sling the psychrometer around for a 30-60 seconds, what do you think would happen to the wet bulb and dry bulb temperatures? Why? Try it and find out.

3. Read and make note of the dry bulb and wet bulb temperatures.

4. Sling the sling psychrometer around for another 30 seconds, and read the dry and wet bulb temperatures again.

5. Keep repeating Step (4) until the temperatures of both bulbs are steady. Record the final temperatures.

6. Using the dew point and relative humidity table(s) provided, look up the dew point temperature and the relative humidity corresponding to the dry bulb and wet bulb temperatures that you measured. (Note that some tables use the "wet bulb depression" instead of the wet bulb temperature. The wet bulb depression is just the difference between the dry bulb and wet bulb temperatures.)

C. **Temperature, pressure, and moisture inside of a bottle** (continued)**.**

You need to know:

- Same things as before.

The experimental setup: a closed, one-gallon, narrow-necked glass bottle with a shallow layer of water at the bottom; a rubber stopper and a vacuum bulb, connected by a flexible rubber or plastic tube; a thermocouple threaded through the stopper with the thermocouple sensor inside the bottle; several wooden matches.

1. [Warm-up questions to think about: What happens to liquid water left sitting around at room temperature? (For example, have you every washed dishes and set them in a dish drainer for a while?) How would the amount of water vapor in the air inside the bottle (that is, the water vapor content of that air) compare to the water vapor content of air outside the bottle? What about the dew point temperature of the air inside the bottle compared to outside? Relative humidity inside vs. outside the bottle? In each case, why?]

2. On the laptop, click on the big, green "Collect" button at the top of the Logger Lite window. If you are prompted about whether you want to continue the previous plot or not, say no (create a new plot).

3. When the temperature inside the bottle is relatively steady, record it.

4. Have someone hold the rubber stopper firmly in place, and a second person shine a flashlight through the bottle from the side. While the stopper continues to be held firmly in place to prevent air from leaking (and the stopper from popping off), a third person should use the vacuum bulb to pump air into the bottle until they can't pump any more in, as before.

5. Wait perhaps 20 seconds, continuing to hold the stopper in place.

6. Continue to shine the flashlight through the bottle. Carefully loosen the stopper until it pops off, but hold it loosely (a) to prevent it from flying away and hitting someone, and (b) to keep the thermocouple sensor inside the bottle. Immediately reinsert the stopper afterwards.

7. If anything inside the bottle that you can see has changed, record the observation.

8. After a short time (less than 30 seconds), click on the big, red button at the top of the Logger Lite window to halt

plotting of the temperature. To adjust the vertical scale on the temperature plot and make it easier to read, click on the "Scale" icon on the tool bar along the top of the Logger Lite window. (The Scale icon has a big blue "A".) Record the change in temperature, if any, that occurred between the time just before you opened the stopper and just after you popped it off.

D. **Temperature, pressure, and moisture inside of a bottle** (continued further)**.**

You need to know:

- Same things as before, plus how to light a wooden match.

The experimental setup: same as before, plus several wooden matches.

1. [Questions to think about: Have you ever been inside of a cloud? (For example, have you ever been in San Francisco in the summer? :-)) What does it look like through the first foot (12 inches) or so in front of your face—can you see the cloud? If there were a cloud like that inside this bottle, do you think you'd be able to see much? What does smoke consist of? Is it a cloud?]]

2. On the laptop, click on the big, green "Collect" button at the top of the Logger Lite window. If you are prompted about whether you want to continue the previous plot or not, say no (create a new plot).

3. Tip the bottle at an angle, making sure that the water inside doesn't get the thermocouple sensor wet. Get ready to remove the stopper briefly, but don't do it yet.

4. Strike a wooden match to light it. Let it burn perhaps halfway, so that it will produce a fair bit of smoke when extinguished.

5. As quickly as you can, remove the rubber stopper, gently blow out the match, and *immediately* drop the smoking match into the bottle, firmly reinsert the stopper, and set the bottle upright.

6. Shine a flashlight through the bottle. [Can you see any smoke inside?]

7. Hold the stopper firmly in place, continue to shine a flashlight through the bottle, and pump air into the bottle until you can't pump any more. [Can you see any smoke inside now?]

8. Wait perhaps 20 seconds, continuing to hold the stopper in place. If Logger Lite has stopped recording the temperature, click on the big, green "Collect" button to restart it, adding the new measurements to the previous plot (rather than starting over with a new one).

9. Continue to shine the flashlight through the bottle. Carefully loosen the stopper until it pops off, but hold it loosely (a) to prevent it from flying away and hitting someone, and (b) to keep the thermocouple sensor inside the bottle. Immediately reinsert the stopper afterwards.

10. If anything inside the bottle that you can see has changed, record the observation.

11. After a short time (less than 30 seconds), click on the big, red button at the top of the Logger Lite window to halt plotting of the temperature. To adjust the vertical scale on the temperature plot and make it easier to read, click on the "Scale" icon on the tool bar along the top of the Logger Lite window. (The Scale icon has a big blue "A".) Record the change in temperature, if any, that occurred between the time just before you opened the stopper and just after you popped it off.