Temperature

Introduction

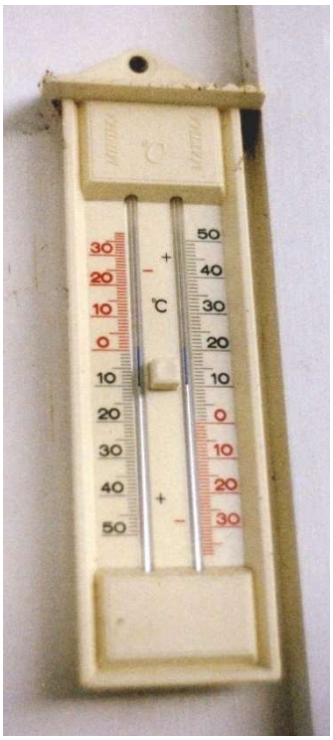

Figure 1. Exterior thermometer. Credit: Uwe W.

Before conducting these investigations, students should be introduced to the properties of air; specifically, having mass and taking up space, exerting pressure, and having inertia which can be seen as it moves or resists moving from place to place (resists being fanned with cardboard sheets). In these investigations, students make observations and measurements of additional properties of air that combine to produce weather conditions. These observations are made at levels appropriate to the students' levels of understanding and skills. This will form the building blocks they will need to understand the molecular nature of atmospheric gases and the kinetics of molecular movement, which are concepts they will develop at later stages of their learning about the natural world.

One property of air that can be measured is its temperature. Air temperature is measured with thermometers. Common thermometers consist of a liquid-in-glass tube attached to a scale. The scale can be marked (graduated) in degrees Celsius (°C) or degrees Fahrenheit (°F) or both. The tube contains a liquid that is supplied from a reservoir or "bulb" at the base of the thermometer. The internal liquid is usually mercury or red-colored alcohol. In the interest of safety, alcohol thermometers are mainly used in schools, since mercury is very toxic.

Alcohol thermometers work due to the expansion and contraction of liquid relative to temperature. As the liquid in the bulb of the thermometer is heated, it expands and rises up in the tube. Conversely, as the liquid in the bulb is cooled, the liquid contracts and falls in the tube. In this investigation, students will develop the concept of expanding liquids on which a liquid-filled thermometer is based, and then apply this knowledge by using an outdoor thermometer to record daily temperatures.

How can we put things in a sequence by how hot they are?

Teaching and Learning Focus

To introduce students to ideas about temperature, they first need to realize that liquids and gases can be warmer or cooler in different situations. This first investigation question is

designed to help students understand that air and water can exist at different temperatures.

Materials Needed

- four foam cups
- markers
- water at different temperatures
- regular alcohol thermometers in °F and °C
- blank alcohol thermometers
- paper towels
- Data Worksheet

Preparation of Materials:
Fill 3 foam drink cups marked A, B and C large enough to put hands in each should contain water at the different temperatures shown in the table.

Cup A	Water slightly warmer than body temperature, about	100 °F/38 °C
Cup B	Cold water at a temperature of about	45 °F/7 °C
Cup C	Water that is at or near room temperature	72 °F/22 °C

A fourth drink cup marked D, with water that is not as hot as cup A, but also not the same as cup B or C.

Safety

This investigation question is considered generally safe to do with students. You should check that the heated water is not too hot to handle. Please review the investigation for your specific setting, materials, students, and conventional safety precautions.

Setting the Scene

To introduce students to ideas about temperature, they first need to realize that materials can exist at different levels of heat. This first investigation is designed to get them started on that learning pathway.

Hold up a cup of very hot water-hot enough that steam is coming off of it. Ask the students to describe it. (Among other things, they will say that it is "hot".) Next, hold up a cup of water that obviously has ice floating in it. Ask students to describe this cup. (Among other things, they will say that it is "cold"). Now, pour some of the hot water and most of the cold water into a third cup and ask students to describe it. (They are likely to say the water is "warm", or it is "cool"). Finally, pour the remaining cold water into the first cup, with the remaining hot water, and ask about it. Among the answers for the last cup are likely to be descriptions including "warm" and "hot", and maybe even "hotter than warm". Some students may revise one or more responses to include "cool" and/or "warm" in place of each other. While terms such as "warm" and "cool" are relative terms, we can get an idea of

how they can be used in a sequence. What if we could not feel how hot something is directly? How else could we put things in sequence by how hot they are?

Presenting the Investigation Question

Introduce students to the investigation question: " How can we put things in a sequence by how hot they are?" Have students discuss the question in pairs, then in groups, and then as a whole class. Record their answers on the flipchart.

Have students brainstorm ideas about how to investigate this question:

1. What materials would be needed?
2. What would you have to do?
3. What would be measured?
4. How long would the experiment take?

Assessing What Your Students Already Know

Show pictures, like the 2 that follow, and ask initial questions that students can discuss in groups then as a whole class:

- What do you think the air would feel like if you were standing here?
- If you were here, how would you be dressed?
- How can you tell when air is cooler than where you are now?
- What might the air temperature be in this place?

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Have students report out their ideas and make a list of them. From their responses you will get a good sense of the understanding they bring to the concept of temperature.

Exploring the Concept

1. Introduce cups of water A, B, and C to students. Have them to feel the water in each then arrange them in the order of coldest to warmest. Ask students to explain how they are distinguishing hot from cold, warm, or cool. What are they using to detect the differences in the water samples?
2. Ask students to think about other ways they could tell the heat differences in the cups?
3. Give students a blank thermometer tube. Ask them to describe what they see. Have students observe and record what happens when they insert the thermometer tube first in B, the cold water, then in C, the warmer water, and finally in A, the hot water.
4. Have students draw what they see on the data worksheet.
5. Immediately following their observations, ask the students to display their drawings so that they can share and compare. The relative height of the red column in each tube is all that is important, not the exact length. As described above, A should be higher than B, and B should be higher than C.
6. Give each group a fourth cup marked D with water that is between the temperatures of those in the first three cups (different groups can have different temperatures from one another.) For safety reasons, do not make the water in the fourth cup hotter than the hottest water, which was in cup A. If possible, have a lid on this cup that allows the thermometer tube to be put through, but does not allow the students to touch the water.
7. Tell the students to determine where this cup should go relative to the other three in the sequence without touching the water in cup D-using only their thermometer tube.
8. Discuss how the placement of cup D was determined by each group. If groups disagree about the placement of D in the sequence, ask them if it might be possible that the groups had water of different temperatures. How could they check that with their equipment? (Place the thermometer tube in cup D for the different groups and compare how long the red column is for each.)

Applying Students' Understanding

To assess students understanding of what a thermometer tube is and how it is used, ask them to describe what they have observed:

What happened as the thermometer tube was placed in each of the four containers? (The level of the liquid in thermometer changed. It was highest in A and lowest in B.)
Help students understand that the warmed liquid takes up more room inside the tube. (When warmed, the liquid expands. That's the way a liquid-filled thermometer works, whether immersed in liquid or hanging in the air. The red coloring is added to make it easier to see.) The thermometer tube provides a reliable way to judge temperature that does not depend on the sense of touch, which can be unreliable under some circumstances.

Revisiting Investigation Question 1

Complete this investigation by asking students to reflect on its investigation question and how their answers may have changed as a result of what they have learned. While our sense of touch allows us to put things in a relative sequence from warmest to coolest, as the differences in temperature become smaller, our sense of touch can be less reliable than an instrument. When we are in situations where we cannot use touch, some kind of instrument must be used.

To help make the point about the sense of touch being unreliable, send one student out of the room for a few moments while you prepare the following demonstration. On a table where all students can see, set up three containers of water that are large enough for a student to place her hand in:

- a container of water that is very warm (but not hot) to the touch,
- a container of water that is very cool to the touch,
- a container of water that is room temperature.

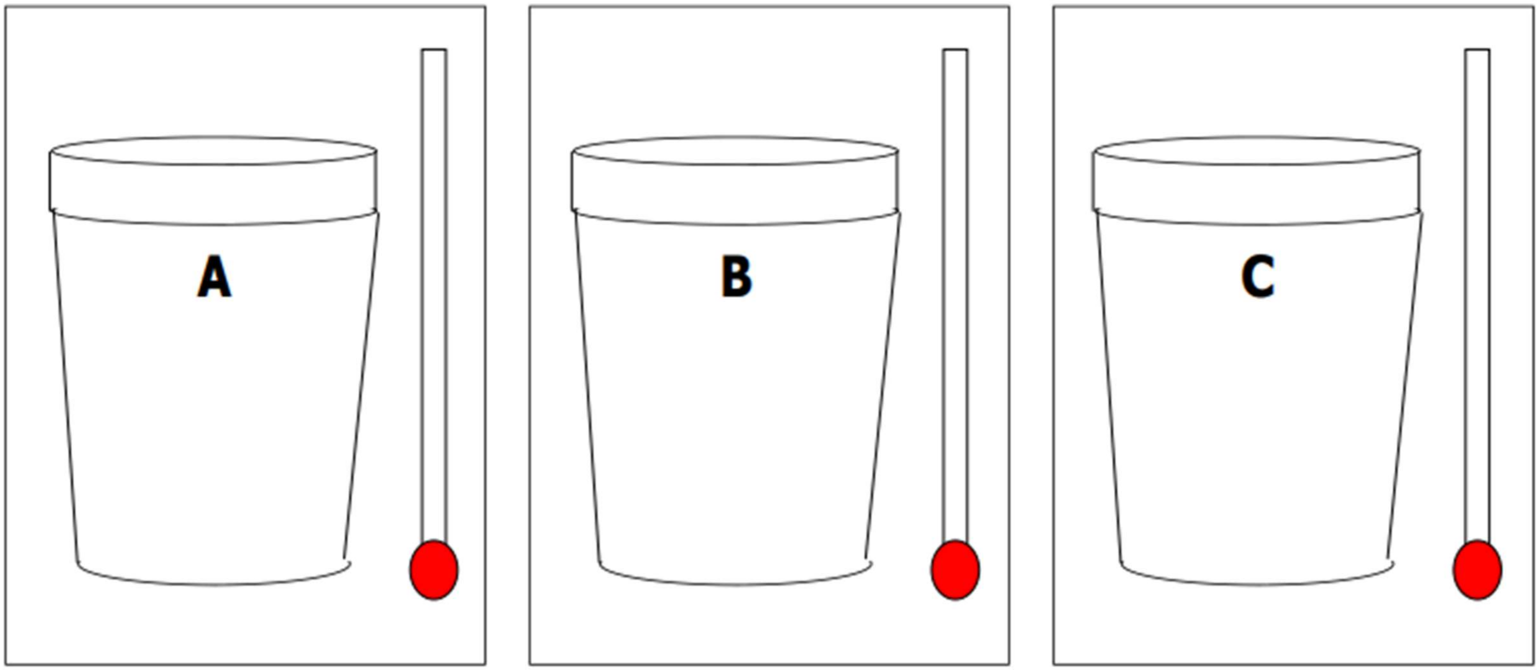
Cover the containers with a towel so they are not visible. Have the student return from the hallway and blindfold her. Explain that she is going to put one hand in warm water and the other in cool water, then you will help her move each to another container. Guide the student's hands into the warm water and the cool water. Then, one at a time, guide her hand into the room temperature water and ask her to describe it to the class. When she moves from the warm water to the room temperature water, she will describe it as cool. When she moves from the cool water to the room temperature water, she will describe it as warm. Touch is a relative sense, in that we sense the difference in temperature between our current sensation and the new one, not the absolute temperature.

Data Worksheet

Name:	Date:

Observation Drawing

How can we put things in a sequence by how hot they are?



How warm or cool is it?

Teaching and Learning Focus

Temperature Investigation Question 1 gave students experience with relative temperature (i.e. warmer, cooler). Your students can be very adept at observing things compared to one another and observing changes. They may have less understanding about how conditions and changes can be measured using units. This investigation will help them understand that temperature can be measured using standard units (in this case degrees Fahrenheit and degrees Celsius.)

Materials Needed

- 4 foam drink cups (Labeled A-D with A-C filled according to the table:
- alcohol thermometers calibrated in °F and °C
- paper towels
- Data Table

Cup A	Water slightly warmer than body temperature, about	100 °F/38 °C
Cup B	Cold water at a temperature of about	45 °F/7 °C
Cup C	Water that is at or near room temperature	72 °F/22 °C

Safety

This investigation question is considered generally safe to do with students. You should check that the heated water is not too hot to handle. Please review the investigation for your specific setting, materials, students, and conventional safety precautions.

Setting the Scene

In the last investigation question students sequenced cups by relative temperature. That works well as long as the cups with water to be compared are very near each other. When comparisons have to be made less directly, problems can arise. To illustrate this you can set three cups around the room, each with a different temperature of water (each should be close room temperature, only a little different from one another.) Have three volunteers help you by standing at each cup. Tell them to sequence the cups by temperature. Tell them to work together, but without moving. They will find it very difficult, since each is unable to compare his cup with the other two. In this case, descriptions do not work well. You can allow the students to move around the room to the other cups, and still it will be difficult to sequence the temperatures. Imagine if this were being done at an even greater distance, such as if you were trying to describe the temperature of the water in the cup to someone in another town (such as for a recipe.) Describing temperature using numbers (i.e. measurements) can help with this kind of communication.

Presenting the Investigation Question

Introduce students to the investigation question: "*How can we describe temperature using numbers?*" Have students discuss the question in pairs, then in groups, and then as a whole class. Record their answers on the flipchart.

Have students brainstorm ideas about how to investigate this question:

1. What materials would be needed?
2. What would you have to do?
3. What would be measured?
4. How long would the experiment take?
5. Assessing What Your Students Already Know

Assessing What Your Students Already Know

From the preceding Temperature Investigation Question 1, students will know that a liquid can exist at different heat levels (i.e. temperatures) and that this can be seen using a blank thermometer. It is also likely that most students will have some idea of temperature measurement. They will probably know that it feels hot outside when people say it is 90 degrees, or cold when the temperature is reported at several degrees below zero. What they may not understand is just what a degree is in terms of a measurement unit. They may also not know that there are two different measurement scales, English (Fahrenheit) and metric (Celsius or Centigrade), and that the metric, or Centigrade, is the scale conventionally used in science.

Exploring the Concept

1. Set up cups with three temperatures of water as you did for Temperature Investigation Question 1. Give students calibrated thermometers. Have them repeat the insertions into the three cups as they did in Temperature Investigation Question 1, but this time help them to read and record the different temperatures in both degrees Fahrenheit and degrees Centigrade. As they did before, they can determine the sequence of the cups based on temperature, but this time using measurements instead of a relative scale. To do this they can construct a chart like the one below, or a computer version (*Your students should learn that it is important in science to use tools, such as computers and calculators, observational procedures and recording techniques such as tables*).
2. Now have students look closely at two measurements, °F and °C. Ask them to note and discuss the differences (*This is a good opportunity to introduce the idea that for a unit of measurement to work, a group of people have to all agree to use it. The Fahrenheit and Celsius scales are usually included on thermometers because each is used by different groups - Fahrenheit, which is an older traditional measure, is used in the United States, Celsius, which is newer, is used in most other countries in the world. Celsius is also the unit mostly used by scientists.*)

3. Provide a cup D (with a lid if possible) with water within the range of the temperatures of cups A through D, and have the students again add it to the sequence, but this time using the temperature measurement of the water in the cup. Do all the groups have water the same temperature in the cup marked D? How does measuring make it easier to answer that than it was in Temperature Investigation Question 1 with just relative comparisons to use?
4. Get students to think about air and how it is often cooler at some times, or in some places, than others. Let them see what the temperature is in the classroom. (*You can ask different students in different parts of the room call out their observed temperatures to see if they are the same or different in one area of the room and another.*.)
5. If the outside air is quite different to the classroom temperature (hot or cold day) have students go outside to measure and record the air temperature. (*This is an opportunity to help students see temperature of air is an important part of "weather". Again, as in the classroom, different locations have specific conditions*.)
6. Tell the students that they will record the outdoor temperature daily for ten school days. They will describe current weather conditions throughout the period. They will also record other factors to describe the conditions and to compare one day to the others. (*Your students should devise a good way of recording this information. Help them to design an appropriate chart, computer data program, or other method.*)
7. Ask the students why it will be important to record the temperature in the same location and at the same time each day. (*Even young children will see the need for such controls in keeping records. You might reinforce this by asking if it would be fair to measure the temperature at different times of day as they compare one day's conditions to the next.*)

Applying Students' Understanding

To assess how students understand how measuring air with a thermometer is related to weather show them a local newspaper weather report and/or a video recording of a television weather forecast. Ask them to:

- find as many connections they can between their temperature recordings and the information given in the reports and forecasts;
- discuss why air temperature is usually shown and why people often want to know about it.

Revisiting Investigation Question 2

Complete this investigation question by asking students to reflect on "How can we describe temperature using numbers?" and how their answers may have changed as a result of what they have learned. While numbers can express relative temperature (1st, 2nd, 3rd), using a standard temperature scale with degrees Fahrenheit or Celsius allows for descriptions and comparisons across distances and over time.

Data Table

Name:	Date:

Observation Table 1
How warm or cold is it?

TEMPERATURE MEASUREMENTS – DIFFERENT CUPS			
Cup	**Sequence**	**Degrees Fahrenheit**	**Degrees Celsius**
A			
B			
C			
D			

How much can air temperature change during a day?

Teaching and Learning Focus

Your students now have an understanding of how a thermometer works and the way in which they can be used to measure temperature. In this investigation question, students use a thermometer to measure and record the temperature of air outside and inside their school over a period of time.

Materials Needed

For each group:

- Thermometer calibrated in Fahrenheit and Centigrade
- Recording chart (see blackline master)
- Clipboard (optional)
- Pencil
- Clock or watch

Safety

This investigation is considered generally safe to do with students. Please review the investigation for your specific setting, materials, students, and conventional safety precautions.

Setting the Scene

Using data from a local newspaper or almanac, show students several different temperature reports for your location all attributed to the same date. Include a daily high, daily low, record high, record low, noontime temperature and so on, so that while all the temperatures are truly for your location, they are actually somewhat different in what they report. Ask the students how it can be that so many temperatures can be attributed to the same place and on the same date. As the idea of the temperatures being for different times (among other differences) emerges, introduce the investigation question.

Presenting the Investigation Question

Introduce students to the investigation question: "*How much can air temperature change during a day?*" Have students discuss the question in pairs, then in groups, and then as a whole class. Record their answers on the flipchart.

Have students brainstorm ideas about how to investigate this question:

1. What materials would be needed?
2. What would you have to do?
3. What would be measured?
4. How long would the experiment take?

Assessing What Your Students Already Know

Your students will know that outside temperature can vary. They will certainly know of seasonal differences, and most will know that it's usually warmer in the daytime and cooler at night. Many will know that it is usually cooler in the morning and evenings. They may connect this idea with the position of the Sun in the sky. What they may not know is the extent to which temperature can rise and fall over a period of time in one day (i.e. the typical daily temperature range). Ask you students to consider these questions, first in pairs, then in groups and then as a whole class:

- Does the outside air temperature change during a day?
- When during the day is it the coolest outside?
- When during the day is it the warmest outside?
- Does the air temperature inside the school (or home) change during a day?
- How could you find answers to these questions?

Exploring the Concept

1. In the classroom, give each group its thermometer. Have students check it and read the temperature it is showing in both degrees Fahrenheit and Centigrade.
2. Ask each group to report their measurement. (*This can be a reality check for you: they should all be roughly the same. If not, then either a thermometer is faulty or the group does not know how to read the measurement.*)
3. Now tell students that they are going to do this again every hour for the rest of the day. Tell them also that they will be measuring the outside temperature every hour as well. Ask them what would be a good way of recording these measurements. (*Some may say to write them up on the board, or onto a piece of paper. Accept all ideas - do not say any method a student offers is incorrect. If students do not suggest using a data table, steer students toward that idea.*)
4. Work with students to build a table that will fit the observational task. If they come up with a workable chart or method accept it and proceed. If not you can lead them toward the one shown below. (*It is important that students learn about tables and how they can be constructed. Point out the features.*)
5. Help students to see how the symbols "ºC" and "ºF" can be used to simplify recording. (*You do not necessarily need to spend time trying to explain what a ·degree· means in this context - that can come later.*)
6. Now ask students to think about today's weather. You can use questions like this to promote discussion:
   · Is it warmer or cooler outside right now than it was yesterday?
   · Do you think it will remain the same all day - get warmer/cooler?
   · Will it be different in different places - sunny place, shaded place?
   · What about inside the building - will the temperature vary there?
7. Have your student groups develop predictions based on what they already know about daily weather. Encourage them to be as precise as they can be with these. Here are some likely candidates for predictions:

- The outside air temperature will rise at first then begin to fall.
· The outside air temperature will continue to rise.
· The outside air temperature will fall throughout the day.
· The outside air temperature will be different in different places (*sunny place, shady place.*)
· The outside air will have a wider range of temperature than the inside air over time.
· The inside air temperature will remain the same all day.
· The inside air temperature will be different in different places (*sunny window, shady cupboard.*)

(*You will need to decide just how wide you want this investigation to be. You could have all students follow just one prediction. Everyone can make the same observations and measurement with regard to the same prediction. The advantage here is that it is easy to organize and data can be pooled to check reliability - a common scientific practice. On the other hand, you could broaden this out so that different groups are observing and recording different aspects of air temperature. For example, if each group records temperature in a different place in the schoolyard, it is likely that their results will differ somewhat. This is why, for example, the National Oceanic and Atmospheric Administration-NOAA-has established standards for the siting of thermometers used for official measurements-see the NOAA website for details. Varying the sites at which measurements are taken allows the class to cover a much wider range of factors and allows different groups to specialize then share their findings - another common scientific procedure. You decide!*)

8. Make sure that each student group writes down its prediction(s) and the reasons for them. Tell them that they will look again at these when they have made and recorded their observations.
9. Find a way for students to test their predictions by taking their temperature measurements on an hourly basis throughout the school day. This may need some organizing ahead of time. Individual students within the groups can take turns in doing this - slipping outside, or within the building, to take and log a reading. (*It might be good to alert your administration and colleagues that this is going to happen, just to avoid misunderstandings*.)
10. When all measurements have been taken, have each group revisit the prediction(s) it made. The group can then judge whether the prediction(s) is/are supported or not supported by the data. (*Either way is important. If a prediction is proved correct, it confirms the reasoning. Even if a prediction is not supported, it is still useful - it helps to rule out the reasoning so "we know that's not the explanation, it must be something else." Help students to see that all results can be helpful in science.*)

Applying Students' Understanding

To check how well students have grasped the concepts of air temperature measurement, you could have them apply it more broadly. Ask them to construct a table into which they could enter daily temperatures over a longer period of time (*a week, a month, three months, a year, etc.*) Challenge them to come up with a plan to put temperature measurement into a school weather center. A sample data sheet is included.

Revisiting Investigation Question 3

Complete this investigation question by asking students to reflect on "How much can air temperature change during a day?" and how their answers may have changed as a result of what they have learned. The range of temperature extremes (daily high temperature compared to daily low temperature) varies considerably for different locations. A record of the daily highs and lows for some U.S. locations can be found on the NOAA website.

Revisit the Concept of Temperature

As soon as you have finished the investigation above, ask students to think about the differences between measuring the temperature of water and the temperature of air. How are they similar and how are they different. You could ask them how they might measure the temperature of a solid material as well.

Let students discuss the importance of measuring air temperature accurately. What might happen if the temperature is misread? How could they check that a thermometer is reasonably accurate - correctly calibrated? (They could do this by using several thermometers at the same time. They should all read about the same. If one is different, it's probably faulty. If they are all the same the fault lies with the observer!)
It might be interesting to have students explore connections between air temperature and environmental conditions. Ask them what kinds of animals and plants live in extreme temperature conditions, both hot and cold.

Linking to Weather
Your students may need help in understanding air, or atmospheric conditions, are key components of weather scientists measure and track. They need to begin to understand that air temperature plays a big role in determining weather conditions and patterns.

In further investigations, students will be making air measurements and atmospheric observations similar to those used by scientists to make predictions about everyday weather.

Digging Deeper

Elements of Weather

All sciences begin with observations. Without observations, scientists have no way to develop new theories and to test existing theories. The weather is no exception. Meteorologists (scientists who study the weather) observe many elements of the weather, both at the Earth's surface and at high altitudes. Weather observations are used for predicting the weather and for developing and testing new theories about how the weather works.

Air Temperature

Air consists of gas molecules, which are combinations of two or more atoms. Although you cannot see them with your eyes, the molecules are constantly moving this way and that at very high speeds. As they move, they collide with one another and with solid surfaces. The temperature of the air is a measure of how quickly the molecules are moving. The more energy of motion the molecules have, the higher the temperature you feel in the air.

Air temperature is measured with thermometers. Common thermometers consist of a glass rod with a very thin tube in it. The tube contains a liquid that is supplied from a reservoir, or "bulb," at the base of the thermometer. Sometimes the liquid is mercury, and sometimes it is red-colored alcohol. As the temperature of the liquid in the bulb rises, the liquid expands. As the liquid expands, it rises up in the tube. The tube is marked with a scale, in degrees Fahrenheit or in degrees Celsius.

When you are measuring the air temperature, be sure to have the thermometer in the shade. If the sun shines on the thermometer, it heats the liquid. Then the reading is higher than the true air temperature. Also, when you take the thermometer outside, give it enough time to adjust to the outdoor air temperature. That might take several minutes.

Aire Temperature Data

Name:	Date:

Observation Table
How much can air temperature change during the day?

AIR TEMPERATURE MEASUREMENTS OVER TIME				
	Inside (*state where*)		Outside: (*state where*)	
Time	°C	°F	°C	°F
8:00am				
9:00am				
10:00am				
11:00am				
noon				
1:00pm				
2:00pm				
3:00pm				