In this laboratory exercise you will learn about some of the many factors that influence temperature at the surface of the earth and in the atmosphere.

Simply stated, temperature is that particular property of an object which allows it to pass heat from itself to other objects. This heat exchange occurs provided that the temperature of the original object is higher than any of the other objects. Thus, if two spheres are placed side by side heat will flow from the sphere with the higher temperature to the sphere with the lower temperature. Or, if a cloud passes over a field on a summer afternoon, heat will flow from the unshaded area, which is hotter, to the shaded area, where it is cooler. This “differential heating” leads to several very interesting meteorological phenomena.

Temperature measuring is based on the principle that when an object is heated the molecules that make up the object move faster. This is the principle behind the use of the thermometer, which, in most cases, is simply a closed glass tube partially filled with some suitable liquid. As the temperature increases the molecules move faster, push outward and try to take up more space within the glass tube. When you look at a thermometer, what you see is the fluid rising in the tube (when the thermometer is being subject to heating) which is a result of the accelerated molecular movement of the fluid. As the temperature cools, the molecules move more slowly in the glass tube, you see the fluid shrinking, indicating that the temperature is decreasing.

Liquid-in-glass thermometers were invented early in the seventeenth century. The most common fluid used in thermometers, for meteorological work, is mercury; however, colored alcohol is also used. Another type of thermometer which is used widely around the home is the bimetallic thermometer. These are inexpensive instruments which are commonly used in ovens or outdoors and are easily recognizable by the metal coil contained inside. However, what appears to be a single strip of metal is actually two strips of dissimilar metal (hence, bi-metal) welded or riveted together. Based on the principle that different metals expand and contract at different rates at different temperatures, as the temperature changes, the coil “unwinds” or “winds” (because of the fact that one of the metals is changing its shape more than the other). This motion is then communicated to a pointer which moves over a calibrated scale on which you read the temperature. This simple, inexpensive instrument is not greatly accurate since, because of friction between the moving parts, some motion is lost and erroneous temperature readings may result.

Temperature Scales

There are several temperature scales in use. The most common scale in the United States is the Fahrenheit (°F) scale. For scientific work and in use in most European countries is the Centigrade or Celsius (°C) scale. A temperature of 32° on the Fahrenheit scale corresponds to 0° on the Celsius scale. 212°F corresponds to 100°C.

Conversion from one scale to the other can be made by use of the following:

\[ °F = \left(\frac{9}{5} \times °C\right) + 32 \]

\[ °C = \frac{5}{9} (°F - 32) \]

Another scale used widely in scientific work is the Absolute or Kelvin (°K) scale. The conversion from degrees Celsius to degrees Kelvin can be made by using \[ °K = °C + 273°. \]
Problem 1-1a

Complete the following table:

<table>
<thead>
<tr>
<th>°F</th>
<th>°C</th>
<th>°K</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Problem 1-1b

At what temperature do Fahrenheit and Celsius scales agree?

Isoplething—the Analysis of Numerical Fields

When looking at a weather map on which temperatures are plotted, it becomes useful to be able to pick out certain temperature patterns easily. That is, which are the warm areas, which are the cold areas, etc. Also, temperatures cannot be known at every point on the map; that is, at every 50 or even 100 or 200 miles, simply because the cost would be enormous. In this case, the concept of isoplething or the analysis of temperature fields becomes useful.

For example, say you know the temperatures (°F) at points A, B, C and D below. What would be a reasonable guess of the temperature at E?

55 °A
56 °B
59 °C
58 °D

If you were driving your car from A to D, you would experience temperatures of 55°, 56°, 57°, and then 58°. Could you say that the temperature at E is 57°? Is this consistent if you drove from B to C? Here your thermometer would register temperatures of 56°, 57°, 58°, then 59°. Therefore, it is reasonable to assume that the temperature at E is 57°.

Problem 1-2

Make a reasonable guess at the temperature (°F) for the points not given.

62.
72.
75.
77.
63.
66.
65.
78.
80.
82.
Meteorologists speak of temperatures presented in this manner as a temperature field.

Note in the second part of problem 2, that the determination of the temperatures at the unknown points is more difficult. The reason for this is simply that there are more points to look at and more combinations to consider. If this seems difficult with only six points, think how it would be if you looked at a weather map with several hundred points on it.

To alleviate this forest versus trees type of problem, meteorologists employ the useful operation known as “isoplething.” Isopleth is a Greek word meaning equal (iso)—value (pleth). Simply stated it means to connect equal values of the particular meteorological variable with which you are working with a line. In the case of temperature, the isopleths (which is a general term) are called isotherms and the operation can best be explained by an example.

![Figure 1-1](image)

**Figure 1-1.** Notice that in this figure the isoplething has been done at 5° intervals. That is, there is a 70° isotherm, a 75° isotherm, and an 80° isotherm. This is not a set rule, since isoplething can be done at any interval desired.

In most cases, the isoplething is not as simple as in the above example. Figure 1-2a shows a temperature field (°F) that is more complicated.

![Figure 1-2a](image)
However, after drawing isotherms, in figure 1–2b the field is much easier to study. It doesn’t look so confusing. In other words, *isoplething is a means of organizing the data.* Once the field has been isoplethed, it is said that the field has been “analyzed.”

![Figure 1–2b](image-url)

**Problem 1–3**

In figure 1–2b make a reasonable guess at what the temperatures are at points A, B, C, D, which are marked with a ☺.

A _____ °F B _____ °F C _____ °F D _____ °F
Problem 1-4
Isopleth the following temperature field at 5°F intervals. What is the temperature at A? ______ at B? ________ Hint: use a soft (#2) pencil; sketch in your lines lightly until you are satisfied. Then darken them.

Problem 1-5
Analyze the following temperature field by drawing the 70°F isotherm. Then draw other isotherms at 5°F intervals such as 65°F, 75°F, 80°F, etc. Then determine the temperatures at A and B.
Problem 1–6

What is the value of isoplething? Why do meteorologists spend time isoplething temperature fields?

Radiosonde Observations of Temperature

One of the most valuable pieces of equipment available to the meteorologist is the radiosonde. Carried aloft by balloons, the radiosonde consists of a moisture sensing instrument, a pressure sensing instrument and a device for measuring temperature. The balloon transporting the instrument package ascends at a rate of about 1,000 feet per minute up to an altitude near 50,000 feet and information gained by the sensors is transmitted by FM radio back to earth. These data are known as a “sounding” and the sounding is usually plotted on meteorological diagrams to give a picture of the vertical structure of the atmosphere.

The atmosphere has a nearly characteristic temperature structure in the vertical. This structure has been determined not only by radiosonde observations, but also by rockets and satellites which carry meteorological instruments. Figure 1–3 depicts a typical or average temperature sounding from the surface to a height of 110 miles. This graph shows that from the surface to about 8 miles atmospheric temperature decreases quite sharply. This region is known as the troposphere and is “capped” by the tropopause which is the height where the first minimum temperature is reached. From the tropopause to an altitude of about 20 miles the temperature remains nearly constant (does not change) with height. From 20 miles to about 30 miles, the temperature begins to increase with height reaching a maximum at the stratopause which is the “top” of the stratosphere. For the next several miles the temperature remains about constant again, but at about 40 miles it begins to decrease, reaching another minimum at 50 miles. This third atmospheric layer is known as the mesosphere and, as you may have guessed, the top of the mesosphere is the mesopause. From the mesopause upwards the temperature increases, quite sharply at first, then less and less until it reaches a maximum of about 1,500°C at 300 miles. This last layer is known as the thermosphere.

For most work, however, the meteorologist is not concerned with the atmosphere above the tropopause. In fact, meteorologists do not even use altitude as one of the coordinates on their diagrams preferring, instead, to scale the atmosphere according to pressure.

Atmospheric pressure can be illustrated by considering a pile of 5 bricks. Assume each brick weighs 2 pounds. If you were to put a scale at the bottom of the pile, it would register 10 pounds. If you put it under the third brick, the scale would register 6 pounds, and so on.

Air, like the bricks, has weight and the atmosphere above you “weighs” the most at the bottom and less as you go up, since there is less atmosphere, i.e. less weight, over you. Unlike the bricks where “a change of one brick is a change of 2 pounds,” atmospheric pressure changes in the vertical most rapidly near the ground and less and less rapidly as you ascend to greater altitude. Figure 1–4 illustrates this concept with the vertical coordinate scaled by pressure units.

Now, graphing the atmosphere’s vertical temperature structure using pressure as the vertical coordinate we get the result shown in figure 1–5. A height scale is also included for reference.
By comparing figure 1–5 with figure 1–3 it can be seen that except for the troposphere and a portion of the stratosphere the other atmospheric layers are not included when scaling the vertical according to pressure. In meteorology, this is by far the most practical manner to illustrate the vertical structure of the atmosphere since most of the world’s weather occurs in the troposphere. In fact, for most work, meteorologists consider 100 millibars (a pressure unit—illustrated by 1 in figures 1–4 and 1–5) to be the “top” of the weather. The levels above 100 mb are not normally included on such charts for conventional meteorological analysis.

Temperature and Elevation

It is common knowledge that snow covers the highest mountain peaks in the summer and, in the winter, forecasts of “rain with chance of snow in the higher elevations” are often heard in hilly regions. Indeed, most people have experienced cooling temperatures during leisurely rides up gently sloping mountains. The cause of this temperature change with altitude is linked to changes in pressure and volume.

As already stated atmospheric pressure changes most rapidly in the vertical. Since pressure is a force (per unit area), consider a cube of air being acted on by this pressure force. As the cube of air rises, the pressure decreases and so the force acting on sides of the cube becomes less. Now the cube can expand since the “force” acting on the walls is less. As the cube continues to rise, the pressure force becomes less and less and it can continue to expand.

But does this affect the temperature? And if so, how? For an answer try spraying the contents of an aerosol can onto your hand. No matter where the can was stored, the spray will be cool. For the liquid, as it is released from the can, experiences a rapid decrease in pressure and a rapid expansion. What if you tried to put the liquid back into the can? You would need to exert a force on the liquid to compress it to a small size to fit into the can. This would cause the temperature of the liquid in the can to rise. The same thing can be done with a tire. Pump it up and the air will warm. (Feel the tire valve.) Let the air out and it will be cool.
To summarize, then, air that rises goes through a reduction in pressure, it expands and, therefore, cools. Conversely, air that sinks, experiences an increase in pressure, hence, it is squeezed together, and the temperature rises. Or to put it another way, when our “box” of air (meteorologists refer to this as a “parcel”) is displaced in the vertical and the temperature of the air in the parcel is not affected by radiation (the sun heating the parcel) or by mixing with the surroundings, (that is, the imaginary walls let nothing in or out) and the air that makes up the parcel is dry, then the parcel will change temperature by $5^{\frac{3}{4}}^\circ F$ for every 1,000 feet of vertical movement (up or down).

The rate of decrease of temperature with height is known as a lapse rate and this $5^{\frac{3}{4}}^\circ F/1,000$ ft is specifically known as the dry-adiabatic lapse rate (meaning there is no moisture in the parcel and there is no heat being added to or lost by the parcel).

**Problem 1–7**

A parcel at the ground is lifted dry adiabatically to 8,000 feet. Its original temperature is $52^\circ F$. What is the final temperature?

**Problem 1–8**

The lapse rate in $^\circ C$ and meters is $1^\circ C$ for every 100 meters (1 meter = 3.3 ft). A parcel sinks from 1,500 m to 900 m. If the original parcel temperature is $-2^\circ C$, what is the final temperature of the parcel?

From the previous two sections, one fact should be quite apparent: in the portion of the atmosphere where most of the world’s weather takes place (which is the troposphere) the temperature normally tends to decrease with increasing height and increase with decreasing height. But, unfortunately, this is not always the case.

On any clear night, close to the ground, the temperature may increase rather than decrease with height. This can occur in almost any locale due to the great amount of heat leaving the earth and flowing back into space. This great loss of surface warmth can cause the air near the ground to be as much as $10^\circ C$ colder than the air two or three thousand feet above it. Conditions such as this where the temperature increases with height are known as temperature inversions. Figure 1–6 shows graphically the differences between normal dry-adiabatic atmospheric lapse rates and lapse rates during inversions.

It is well to point out here that the atmospheric lapse rate is not always dry adiabatic. Remember the somewhat stringent conditions placed on the parcel to warm or cool adiabatically; dry, no radiation loss or
gain, and no mixing with the environment. If these conditions are violated, the lapse rate will be different than the dry-adiabatic lapse rate.

Problem 1–9

Why must the sky be clear for a temperature inversion to occur at the surface?

The Greenhouse Effect

On a cloudy night more heat is radiated back to earth than on a clear night. This results in a warmer surface temperature than if the sky were clear which would allow the heat to escape to space and allow the surface to cool. In a manner somewhat analogous to this phenomena, the entire atmosphere acts as a blanket to keep the earth from becoming a vast, frozen wasteland during the night.

The surface temperature of the sun is about 6,000°K (10,340°F). At this temperature, energy leaving the sun is mainly in a form known as short-wave radiation (i.e. visible sunlight). The atmosphere is transparent for much short-wave radiation and, as a result, this energy can penetrate the atmosphere and warm the earth. The earth will also radiate energy, but because its temperature is relatively low (say, 290° to 300°K) it radiates energy in an invisible form known as long-wave radiation. The atmosphere is not transparent to most of this long-wave radiation which is absorbed by the atmosphere thereby trapping the energy. This entire process is similar to what was once thought to occur in a greenhouse (hence, "The Greenhouse Effect") with the panes of glass acting as the atmosphere which allow the short-wave radiation to penetrate to the plants and soil inside the greenhouse. This "mini-Earth" upon warming radiates long-wave radiation which cannot penetrate the glass (atmosphere) thus allowing the inside of the greenhouse to stay warm.

Problem 1–10

The greenhouse was once thought to produce an effect almost identical to the earth's atmosphere as explained above. Over the years, however, it has been determined that the air in the greenhouse does not stay warm for exactly the same reasons that the earth does. Along with the fact that the glass is transparent
to short-wave radiation and opaque to some long-wave radiation, there is in fact another reason. Take a look at this diagram. Can you think of this reason?

![Diagram showing temperature differences and wind direction](image)

**Temperature and Surface Covering**

As well as being affected by elevation and terrain, temperature is also affected by surface covering. The surface covering of a region is predominantly affected by the amount of moisture in the atmosphere and it is the moisture at the surface which plays a large part in determining how high the surface temperature will rise.

The main direction of flow of air in the United States is from west to east (the "westerlies"). In other words, air coming off the Pacific will gradually move to the Atlantic. It is this westerly flow of air which gives rise to the vast expanses of desert east of the Rockies. Air, flowing off the Pacific Coast is very moist, having gained this moisture from the ocean. As it moves inland to the Rocky Mountains it is forced to rise to great heights. This upward motion causes the moisture in the air to condense and fall out as rain or snow. Upon descending the mountains the air is now dry and this dry air promotes vast regions of clear skies east of the mountains (since the moisture that must be present for clouds to form is not available). With few clouds in the sky to block out the rays of the sun, the temperature in this region can become very hot. However this is only part of the story, for the lack of clouds also means there is a lack of rain, which means that the surface is very dry. Because of this, there is no water in the ground, on the ground, or above the ground contained in plants to be evaporated. Lack of evaporation means that all of the energy reaching the earth is used to heat the surface because no energy is used to evaporate water. Deserts, then, form because there is a high degree of incoming solar radiation (insolation) and because there is no water present to be evaporated which would cool the air. (By the same token, the lack of clouds means that at night the heat stored in the ground can readily escape to space allowing the desert to become very cold.)

Perhaps you can now see why farm fields and other areas with vegetation do not become so hot. Moving eastward towards the Atlantic Ocean, we again pick up sources of moisture (the Atlantic Ocean and the Gulf of Mexico). Therefore, there should be more clouds, hence less insolation, and also more rain.
The increase of rain allows plants to grow and water to be stored in the ground. Evaporation of the water in these “reservoirs” causes the air to cool because, again, evaporation is a cooling process.

In this discussion don’t be misled into thinking that all of this must happen on such a large scale. Let us say that a shower wets one side of a street but not the other side. Which side will have the cooler temperature? The wet side, of course, since there is moisture to be evaporated. In fact, the wet side of the street will continue to be cooler until all the moisture is evaporated (therefore all of the cooling is finished), and the street is heated up to the temperature of the previously dry ground.

Diurnal Temperature Variations

The sun is highest in the sky at about noon each day. Therefore, it would be at this time that the sun’s rays would be striking the earth most directly (that is, the angle between the sun’s rays and the earth is the largest). This, then, should be the time of day when the maximum temperature should occur since the concentration of solar energy on the surface is greatest. But is it? Think for a minute of those warm, summer afternoons by the pool or the beach. Are you hotter at noon or at three or four o’clock? If you spend any time outdoors, especially in the summer, you probably remember being warmer at mid-afternoon, about three o’clock, than at noon. So does this mean that the concept discussed above about the sun angle is in error or are there other processes taking place? The latter of course is true, and to explain it, return once again to what has been said about the earth being both a receiver and emitter of radiation.

At all times of the day, the earth receives and emits energy. During the morning hours, however, when the sun is rising and moving across the sky, the earth receives more energy than it emits and this causes the temperature to rise. It is not until the reception and emission of radiation are equal that the time of maximum temperature occurs. After this point, the earth begins to emit more than it receives and the temperature begins to decrease. The time of minimum temperature, then, occurs when the emission once again balances the reception of energy. This usually occurs shortly after dawn.

**Problem 1–11**

You might be hotter at three or four o’clock in the summer but at what time would the solar radiation do more damage to your skin? Explain.

**Problem 1–12**

The following are data of the average temperature (°F) for each hour of day at Pittsburgh, Pa., during May 1963. Plot the data on a graph and use it to explain the ideas of the preceding section.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Midnight</td>
<td>51°</td>
<td>6 a.m.</td>
<td>47°</td>
<td>noon</td>
<td>64°</td>
<td>6 p.m.</td>
<td>64°</td>
</tr>
<tr>
<td>1 a.m.</td>
<td>50°</td>
<td>7 a.m.</td>
<td>50°</td>
<td>1 p.m.</td>
<td>66°</td>
<td>7 p.m.</td>
<td>62°</td>
</tr>
<tr>
<td>2 a.m.</td>
<td>49°</td>
<td>8 a.m.</td>
<td>54°</td>
<td>2 p.m.</td>
<td>66°</td>
<td>8 p.m.</td>
<td>59°</td>
</tr>
<tr>
<td>3 a.m.</td>
<td>48°</td>
<td>9 a.m.</td>
<td>58°</td>
<td>3 p.m.</td>
<td>67°</td>
<td>9 p.m.</td>
<td>57°</td>
</tr>
<tr>
<td>4 a.m.</td>
<td>47°</td>
<td>10 a.m.</td>
<td>60°</td>
<td>4 p.m.</td>
<td>67°</td>
<td>10 p.m.</td>
<td>55°</td>
</tr>
<tr>
<td>5 a.m.</td>
<td>46°</td>
<td>11 a.m.</td>
<td>62°</td>
<td>5 p.m.</td>
<td>66°</td>
<td>11 p.m.</td>
<td>54°</td>
</tr>
</tbody>
</table>
Summary

This exercise on temperature has attempted to give some useful information to explain many everyday occurrences which you experience, but may not be able to readily explain. It also contains much introductory material for discussions to come. In other words temperature is not just something interesting to broadcast over the radio each day, but a knowledge of temperature and temperature patterns can be used to predict the occurrence of many other meteorological phenomena. For example, knowing what the lapse rate is on a particular summer day is useful in determining whether or not thunderstorms may form. The latitudinal temperature variations throughout the year (to be discussed later) are directly related to the intensity of major storms between winter and summer. The differences in temperature between water and land are directly related to upper air patterns throughout the year as well as playing a role in snowfall intensity near the Great Lakes in winter. And, finally, many of the things discussed so far can be tied together in order to predict the maximum temperature for a particular day, among them the atmosphere's ability to absorb and reflect solar radiation and the amount of evaporation that may occur. Many of the ideas represented here will be drawn upon in future discussions.