Vertical Structure of the Atmosphere

Materials Needed
- calculator
- ruler

Introduction
Our first lab introduces the concept of atmospheric pressure. We will construct and interpret a number of graphs to measure how pressure, density, and temperature change with height above the earth’s surface. We will focus on how these relationships are expressed in the troposphere, which is where most weather processes occur.

Changes in Atmospheric Pressure with Height
The atmosphere is a compressible fluid, made up of gases whose molecules are pulled to the earth’s surface by gravity. As a result, the molecules that make up the atmosphere are most compressed close to the earth’s surface, and atmospheric density decreases most rapidly with height there (Figure 1-1).

Although the boundary between the earth’s surface and the atmosphere is obvious, there is no clear “top” to the atmosphere. It thins out with increasing height, but never actually ends. (The phenomenon is analogous to repeatedly dividing a number in half. Each division produces a smaller number, but theoretically one never reaches zero.) However, since very few gas molecules within earth’s gravitational field exist beyond 100 kilometers (km), we can consider this height an arbitrary “top” to the atmosphere.

We may use a simple rule to describe the rate at which density decreases with height: for every 5.6 km you ascend, there is half the atmospheric mass above you as when you started.

Figure 1-1

1. Using the above rule, indicate the percentage of the atmosphere above and below each height in Table 1-1.
<table>
<thead>
<tr>
<th>Height (km)</th>
<th>% of Atmosphere Above</th>
<th>% of Atmosphere Below</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea level</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

2. Use the data in Table 1-1 to construct a graph on the next page. The vertical axis is divided into 17 equally spaced intervals. Label this axis "Height above Sea Level (km)" and label the intervals. Label the horizontal axis "Percentage of the Atmosphere Above" and label its intervals (0–100%). You will use the graph to answer questions 3–7.

3. Jet airplanes travel at about 11.2 km above sea level (~37,000 ft). Approximately what fraction of the atmosphere is above these jets?

   ____________ %

4. Approximately what fraction is below the summit of Mt. McKinley (Denali) in Alaska (6.19 km, 20,320 ft)?

   ____________ %

5. Approximately what fraction is above Pike’s Peak in Colorado (4.34 km, 14,110 ft)?

   ____________ %

Since barometric pressure reflects the weight of the atmosphere above a point, there is also a close relationship between height and atmospheric pressure. We can assume that 100% of the atmospheric mass lies above sea level and exerts a pressure of approximately 1000 millibars (mb). Since atmospheric mass at 5.6 km is 50% of its sea-level value, the pressure at this height is half of that exerted at sea level.

6. Using this relationship, add a pressure scale beneath the percent scale in your graph and label it “Pressure (mb),”

7. Using this new scale, estimate the pressure at the three levels used above.

   Height of jet airplanes  ____________ mb
   The top of Mt. McKinley  ____________ mb
   The top of Pike’s Peak  ____________ mb
Each atmospheric gas exerts a pressure proportional to its percentage by mass. For example, at sea level nitrogen (N₂) represents 75.5% of the total atmospheric mass and therefore exerts approximately 755 mb (1000 mb • 0.755) of pressure. This relationship is called *Dalton’s law of partial pressure*. Oxygen makes up 23% of the total atmospheric mass.

8. Using *Dalton’s law*, indicate the approximate partial pressure of oxygen at each height below. For the three heights above sea level, calculate the percentage of sea-level oxygen.

- Cruising jet \( \text{mb} \) \( \% \)
- McKinley \( \text{mb} \) \( \% \)
- Pike’s Peak \( \text{mb} \) \( \% \)
- Sea level \( \text{mb} \) \( 100 \% \)

The values above should help you understand why physical activity is more taxing at higher elevations and why jets have pressurized cabins.

### Changes in Temperature with Height

We define four layers of the atmosphere (the *troposphere*, *stratosphere*, *mesosphere*, and *thermosphere*) according to their average lapse rate—the rate at which temperature changes with height (Figure 1-2). Although the lapse rate at any given time or place will differ from this average, the figure provides a starting point for understanding the temperature profile of the atmosphere. The tropopause, stratopause, and mesopause mark the top (end) of each layer.

9. *Ozone is a good absorber of ultraviolet radiation from the sun. How does its highest concentration at 20–30 km influence the stratospheric lapse rate?*

![Figure 1-2. Layers of the atmosphere.](image-url)