A Brief Summary of Some Atmosphere Properties

**Temperature and temperature units**
- Temperature is an indication of and can be used as a measure of stored heat.
- Temperature is measured on either a relative or absolute scale.

- Relative: °C (Celsius)
- Absolute: °K (Kelvin)

Conversion: °K = °C + 273.15

**Atmosphere**

**Composition of the atmosphere**

The atmosphere is composed of a mixture of gases and some particulate matter. The predominant components are:
- Nitrogen
- Oxygen
- Argon
- Carbon dioxide
- Water vapor
- Suspended particles

Proportion of each gas in dry air (excluding water vapor):

<table>
<thead>
<tr>
<th>Component</th>
<th>% by volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>78.09</td>
</tr>
<tr>
<td>Oxygen</td>
<td>20.95</td>
</tr>
<tr>
<td>Argon</td>
<td>0.93</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0.03</td>
</tr>
<tr>
<td>Water vapor</td>
<td>Varies from 0.5 to 4.0</td>
</tr>
</tbody>
</table>

**Vertical structure of the atmosphere**

The vertical structure of the atmosphere can be described in terms of both:
- Temperature variation
- Chemical composition
- Absorption of radiant energy

(See figure 4.3)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Depth (km)</th>
<th>Upper Boundary</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Troposphere</td>
<td>11-16</td>
<td>Tropopause</td>
<td>Temperature decreases with elevation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratosphere</td>
<td>50</td>
<td>Stratopause</td>
</tr>
<tr>
<td>Mesosphere</td>
<td>90</td>
<td>Temperature decreases with elevation</td>
</tr>
<tr>
<td>Thermosphere</td>
<td>700</td>
<td>Temperature increases with elevation</td>
</tr>
<tr>
<td>Exosphere</td>
<td>80,000</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The earth's weather occurs primarily within the troposphere.

**Composition of the atmosphere (continued)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Predominant constituent</th>
<th>Occurs up to 100 km</th>
<th>Primarily as N₂ below 50 km</th>
<th>Primarily as N between 50 and 100 km</th>
<th>Source of nitrogen for the nitrogen cycle - ESL 321</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water vapor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Temperature variation in the troposphere**

In general, temperature decreases with elevation. This can be described by:

\[ T = T_0 - \alpha z \]

where \( T \) is the air temperature at elevation \( z \) above the point where the temperature is \( T_0 \) and \( \alpha \) is the lapse rate, usually expressed in °C/km.

The lapse rate, \( \alpha \), depends on the moisture condition of the atmosphere.

The lapse rate expresses how air cools as it rises, if the cooling is adiabatic.

Adiabatic cooling requires that no energy in the form of heat is lost in the process. Then the temperature variation is simply due to the change in pressure that results.

In the atmosphere, pressure decreases with elevation.
The pressure is a force exerted over a unit area. Pressure in a force exerted over a unit area (newton per square meter or pascal). Pressure is a result of a fluid that exerts from the weight of fluid above that point. Atmospheric Pressure.
Pressure exerted by a column of fluid

Principles:
- Pressure at a point in a static fluid results from the weight of fluid above that point (under natural circumstances)
- Pressure is related to the fluid density since unit weight is related to the density
- Pressure increases with depth in a fluid

Consider the increase in pressure over a small vertical distance $\Delta z$ in a column of fluid with cross-sectional area $A$. The density of the "slice" of fluid is $\rho$. The pressure at $z_2$ is $p_2$ and the pressure at $z_1$ is $p_1$.

Looking at this problem as one of the force increasing as we move down in the column of fluid from $z_2$ to $z_1$, the force exerted on the plane at elevation $z_1$ is the weight force exerted on the at elevation $z_2$ plus the weight of the “slice” of fluid. This can be written as:

\[ p_1 A = p_2 A + \Delta W \]

where $\Delta W$ is the weight of fluid in the slice.

The weight of an object can be written in terms of its unit weight, $\gamma$. In this case:

\[ \Delta W = \gamma \Delta V \]

where $\Delta V$ is the volume of the slice of fluid.

The volume of the slice of fluid can be written as:

\[ \Delta V = A(z_2 - z_1) = A \Delta z \]

\[ p_1 A = \gamma A + \gamma A \Delta z \]

Recall that the unit weight is a function of the fluid density:

\[ \gamma = \rho g \]

where $\rho$ is the density.

Then the equation for the downward force on the plane area at $z_2$ becomes:

\[ p_1 A - p_2 A + \rho g A \Delta z \]

Dividing through by the area of the column, $A$, gives:

\[ p_1 = p_2 + \rho g \Delta z \]

This can also be written as:

\[ p_2 - p_1 = \Delta p = -\rho g (z_2 - z_1) \]

This is one form of the hydrostatic equation showing how pressure changes with elevation in a fluid at rest.

The hydrostatic equation can also be written in differential form. If we let $\Delta z$ and $\Delta p$ shrink to an infinitesimally small quantities the hydrostatic law becomes a differential equation:

\[ dp = -\rho g dz \]

\[ \frac{dp}{dz} = -\rho g \]

\[ \text{gradient of pressure} \]

The interpretation is the same but we can now use it to address the issue of changing density with pressure using the perfect gas law.

Summary:
- $\Delta p$ is the increase in pressure moving downward in a fluid column a distance $h = \Delta z$
- The pressure increase depends on the density of the fluid and the distance itself.
- The hydrostatic equation only strictly applies when the density is constant.
- Pressure is constant on a horizontal plane.

Pressure change in a liquid:

Liquids are considered incompressible under most natural conditions so that the density is considered to be constant. As a result the hydrostatic equation applied directly so that changes in pressure only depend on changes of depth in the liquid.
\frac{dP}{dt} = dP

Substituting this into the differential form of the differential equation yields:

\frac{dP}{dt} = c

The variable \( t \) is related to pressure \( P \).

As a result of this characteristic, the logarithmic law cannot be applied directly.

\text{and} \quad \frac{dP}{dP} = d

where \( P \) is the pressure, \( t \) is the time, \( c \) is the constant. If the pressure \( P \) is not constant but depends on the pressure at

Pressure changes in a gas

in a certain environment, the density of the gas is given by the following equation:

\text{Pressure changes in a different environment, the area of space measured:}

Examples of pressure changes.
The solution of this equation is a function, in this case pressure, \( p \), as a function of elevation, \( z \). But there is one additional complication. The temperature is also known to vary with elevation and is therefore not a constant if the elevation changes a significant amount.

So, we can solve this equation in two ways depending on our assumption about the temperature variation.

**Constant temperature:**

The hydrostatic equation is the simplest case of a differential equation and it can be solved by a technique called the separation of variables where we can simply use what we know about integration to solve the problem.

Since \( R \) and \( g \) are constants and \( T \) is assumed constant, the first step is to separate the variables (\( p \) and \( z \)) and their differentials onto separate sides of the equation. This gives:

\[
\frac{dp}{p} = -\frac{g}{RT} \, dz
\]

With the equation separate, we can simply integrate both sides with the appropriate limits of integration; that is let the pressure at the earth surface where the elevation is \( z = 0 \) be \( p_0 \) the pressure at any arbitrary elevation, \( z \), be \( p \) so that:

\[
\int p_0 \, dp = \int \frac{g}{RT} \, dz
\]

The result of this integration is:

\[
\ln p - \ln p_0 = -\frac{g}{RT} \, z
\]

The equation can also be written in terms of \( p \), as opposed to \( \ln p \), by exponentiating both sides to give:

\[
p = p_0 e^{-\frac{g}{RT} \, z}
\]

So, under the assumption of a constant temperature, pressure decreases exponentially as elevation increases.

**Temperature varies with elevation:**

The more realistic situation is where the variation of temperature with elevation is considered. In this case the temperature is given as:

\[
T = T_0 - \alpha z
\]

Substituting this express for temperature into the differential form of the hydrostatic equation and separating the variables gives:

\[
\int p \, dp = -\frac{g}{R} \int \frac{dz}{(T_0 - \alpha z)}
\]

The integration is similar given a relationship between pressure and elevation as:

\[
\ln p - \ln p_0 = -\frac{g}{R\alpha} \left[ \ln(T_0 - \alpha z) - \ln(T_0) \right]
\]

This can be rearranged and simplified by exponentiating both sides to give:

\[
p = p_0 \left( \frac{T_0 - \alpha z}{T_0} \right)^{\frac{g}{R\alpha}}
\]

**Comparison of the two “models” of pressure variation:**

These two equations are slightly but fundamentally different:

- One is derived assuming the temperature is not a function of either pressure or elevation
- One varies exponentially with elevation while the other varies as the power function

A comparison of the two models, starting with standard atmospheric pressure (1013 mb) at the surface (elevation \( z = 0 \)) shows that:

- The model computations diverge as elevation increases
- They are nearly the same close to the earth surface – within 2 km
- The pressure elevation relationship is nearly linear in the first 2 km
Continue with the composition of the atmosphere.

Example: Pressure variation in the atmosphere.

The pressure in January is 752 mm Hg, while the pressure in July is 748 mm Hg. The average pressure is 750 mm Hg.

In the atmosphere, the pressure is 760 mm Hg.

Comparison of the computed variation of atmospheric pressure with deviation up to 5.

Comparison of the computed variation of atmospheric pressure with deviation up to 10.