Now that we know, more or less, what air is made of, let's talk a bit about it's physical properties.
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Meditations on a Glass of Water

Think about a glass of water for a minute. Depending on how you look at it, there's two ways you might see it:
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- The molecules are continually wandering about the glass, rearranging themselves and bouncing off each other
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This way of looking at things, where we zoom way, way in and see all the granular details, is called the *microscopic perspective*. 
Meditations on a Glass of Water

Think about a glass of water for a minute. Depending on how you look at it, there's two ways you might see it:

- Now suppose we zoomed back out and looked at the glass in a more holistic way
- What we'd see in that case is just some continuous substance, which has weight and exerts a force on the sides of the glass
Meditations on a Glass of Water

Think about a glass of water for a minute. Depending on how you look at it, there's two ways you might see it:

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This other way of looking at it, where we zoom back out and see things as a continuous whole, is called the macroscopic perspective.
Meditations on a Glass of Water

Two different ways of looking at the same thing, both equally valid, depending on your perspective and your interests.

microscopic

macroscopic
Meditations on a Glass of Water

Two different ways of looking at the same thing, both equally valid, depending on your perspective and your interests.

And of course, what was true for water is also true of the air around us!
For the most part, we'll look at air from the macroscopic perspective, in which it's just some continuous substance. Some properties of this substance include:

- **Density:** The density measures the amount of a substance present in a given amount of space. More specifically, it's the ratio of the mass of the substance to the volume occupied:

\[
\text{density} = \frac{\text{mass of air}}{\text{volume occupied}}
\]
Pressure: Pressure is the force exerted by a given volume of air outward on its surroundings. More precisely, the pressure is the force exerted divided by the area of the surface; i.e,

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\]

• From the microscopic perspective, this outward force results from lots and lots of collisions of air molecules across the surface of interest (think air in a tire)
• **Question:** If an air mass always exerts an outward force on its surroundings, why doesn't the mass just always expand?
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• **Answer:** While the air mass exerts an outward force on its surroundings, the surroundings also exert forces back on the air mass.

• In the atmosphere, these *surroundings* are usually other air masses.

![Diagram of three air masses, each exerting pressure forces on the others]
• **Temperature:** The temperature is a measure of the heat energy stored in a substance. More precisely......
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• From the microscopic viewpoint, the temperature measures the speed at which the molecules of air are moving around (on average)

The molecules in warm air move faster than the molecules in cold air.
Pressure and Weight

Consider a column of air extending upward from the ground, and focus on just the part of the column below some height.
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- The air above this height has mass and thus weight, so it pushes downward on our air below.

- **Question:** So why doesn't the air in this upper part simply fall to the ground?
Pressure and Weight

Consider a column of air extending upward from the ground, and focus on just the part of the column below some height:

- The air above this height has mass and thus weight, so it pushes downward on our air below.

**Question:** So why doesn't the air in this upper part simply fall to the ground?

**Answer:** The pressure force from the air below holds it up!
• Now, to keep everything in balance, the pressure force exerted by the air below has to exactly equal the weight of the part of the column above (so that all the forces cancel)

• But of course, there's nothing special about the specific way we divided up our column.....that is, we could have divided the column at any height we chose and the same arguments would apply. Ergo.....
At any given height in the atmosphere, the pressure force at that height has to exactly equal the weight of the air column above that height!

- And since weight is defined in terms of mass by
  \[
  \text{weight} = \text{mass} \times \text{gravity}
  \]

  we can further say that the atmospheric pressure at any given height is determined solely by the mass of air above that height!
• As we move upwards in the atmosphere, the weight of the air above us (and hence the pressure)
As we move upwards in the atmosphere, the weight of the air above us (and hence the pressure) *decreases*

- pressure decreases with height
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And as we move downwards, the weight of the air above us *increases*

- so pressure increases as we move downwards
• As we move upwards in the atmosphere, the weight of the air above us (and hence the pressure) decreases
  - pressure decreases with height

• And as we move downwards, the weight of the air above us increases
  - so pressure increases as we move downwards
Some reference points:

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Typical Pressure (lbs per in²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Commercial jet</strong></td>
<td>10500</td>
</tr>
<tr>
<td><strong>Mt. Everest</strong></td>
<td>8850</td>
</tr>
<tr>
<td><strong>Commuter plane</strong></td>
<td>4500</td>
</tr>
<tr>
<td><strong>Mt. Whitney</strong></td>
<td>4425</td>
</tr>
<tr>
<td><strong>Mexico City</strong></td>
<td>2250</td>
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<tr>
<td><strong>Denver, CO</strong></td>
<td>1600</td>
</tr>
<tr>
<td><strong>World's tallest building</strong></td>
<td>830</td>
</tr>
<tr>
<td><strong>College Station</strong></td>
<td>112</td>
</tr>
<tr>
<td><strong>Sea level</strong></td>
<td>0</td>
</tr>
</tbody>
</table>
The Ideal Gas Law

For a given volume of air, the pressure of the volume depends on two things:
The Ideal Gas Law

For a given volume of air, the pressure of the volume depends on two things:

- The number of molecules in the volume (i.e., the density)

more molecules means more collisions: pressure increases with density! And...
The Ideal Gas Law

For a given volume of air, the pressure of the volume depends on two things:

- The number of molecules in the volume (i.e., the **density**)
- The speed at which the molecules are moving (i.e., the **temperature**)

![Diagram showing molecules in a tire with and without temperature change]

faster molecules means stronger collisions: pressure increases with temperature!
Specifically, the relationship between pressure, temperature and density is given by the **ideal gas law**

\[ p = \rho \, R \, T \]

where

- \( p \): pressure (measured in \( Pa \))
- \( \rho \): density (measured in \( kg/m^3 \))
- \( T \): Temperature (measured in \( K \))
- \( R \): dry air gas constant = 287 \( J \) / \( kg \) \( K \)

As before, we see that pressure increases with both density and temperature.
The Temperature-Density Relation

• According to the ideal gas law, the density can be expressed as

\[ \rho = \frac{p}{R \, T} \]

showing that if we compare two volumes of air at the same pressure, the warmer volume will be less dense.
The Temperature-Density Relation

- According to the ideal gas law, the density can be expressed as

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showing that if we compare two volumes of air at the same pressure, the warmer volume will be less dense.

- Basically, faster molecules tend to spread out more, which makes the volume less dense.
The vertical structure of the atmosphere is divided loosely into four layers based on the vertical temperature profile:

- **Troposphere**: 0-10 km
- **Stratosphere**: 10-50 km
- **Mesosphere**: 50-85 km
- **Thermosphere**: 85 km and beyond

![Diagram of atmospheric layers](https://example.com/atmospheric_layers.png)
Some notes:

- In the absence of solar absorption, the temperature tends to decrease with height (as in the troposphere and mesosphere)
  - **Why?** Because air expands and cools as it rises
- But if solar absorption occurs in a layer, then the temperature can actually increase with height (as in the stratosphere and mesosphere)
- A layer where temperature increases with height is called an inversion
Troposphere:

- On average, the temperature decreases at roughly 6.5 °C / km
- The troposphere contains roughly 90% of the atmosphere's mass, and virtually all weather

Stratosphere:

- Ozone in the stratosphere absorbs UV radiation from the sun, leading to warming of the layer
  - Result: the temperature increases with height

Mesosphere:

Thermosphere:

- Oxygen (O₂) absorbs shortwave radiation, again producing warming of the layer
- The warmest temperatures in the atmosphere are in the thermosphere
In addition to naming the layers, we also name the boundaries between the layers.

85 km tropopause

50 km stratopause

10 km tropopause

85 km mesopause

50 km stratopause

10 km tropopause

thermosphere

mesosphere

stratosphere

troposphere

temperature