Atmospheric Pressure

Strand Matter

Topic Investigating relationships among atmospheric pressure, altitude, and temperature

Primary SOL 6.6 The students will investigate and understand the properties of air and the structure and dynamics of Earth's atmosphere. Key concepts include
a) air is a mixture of gaseous elements and compounds;
b) pressure, temperature, and humidity;
c) atmospheric changes with altitude.

Related SOL 6.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which
g) data are collected, recorded, analyzed, and reported using metric measurements and tools;
h) data are analyzed and communicated through graphical representation.

Background Information

The *pressure* of a gas is related to the number of molecules of gas per unit of volume—i.e., *density*. As the density increases, so does the pressure that the gas molecules exert on their surroundings. The density and, therefore, pressure of atmospheric gases are related to their temperature. As temperature increases, gas molecules move faster and occupy a greater volume. This reduces their density which, in turn, reduces their pressure. Warm gases in the atmosphere are less dense than cold gases in the atmosphere.

Cold, dense gases in the atmosphere tend to sink toward the Earth's surface and are called *cold fronts.* Warm, less dense gases in the atmosphere tend to rise upward away from the Earth's surface and are called *warm fronts.*

The pull of the Earth's gravity is related to the distance from the Earth's center. Gases that are far from the Earth's surface are held together less tightly by gravity than gases that are near the Earth's surface. For this reason, density of gases decreases as distance from Earth's surface increases. Put another way, *air pressure (i.e., density) decreases as altitude increases.*

Temperature varies with altitude, as follows:
- In the troposphere**,** temperature *decreases* as altitude increases.
- In the stratosphere, temperature generally *increases* as altitude *increases* due to the increasing absorption of ultraviolet radiation by the ozone layer.
- In the mesosphere, temperature *decreases* as altitude *increases*, to as low as −93°C.
- In the thermosphere, temperature *increases* at altitude *increases*, to as high as 1,727°C.

Materials

- Large plastic syringes
- Modeling clay
- Hot water baths
- Cold water baths

- Metric rulers
- Graph paper
- Colored pencils
- Pressure sensors
- Copies of the attached handouts

Vocabulary

altitude, cold front, density, mesosphere, pressure, stratosphere, thermosphere, troposphere, warm front

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introduction

1. Assess students' background knowledge of pressure and density. Ask them to relate how diving to the bottom of a swimming pool feels in terms of the pressure of the water on their body, especially their ears. If any students scuba dive, have them extend the discussion by talking about the ever-increasing pressure as one descends to greater depths. Ask students to think about a time when they went to the top of a very tall mountain. Ask, "How did the pressure of the air compare to that at the base of the mountain? Why did your ears 'pop' as you went up? Why did your ears 'close up' as you came down?" Make sure students relate decrease of air pressure with increase of altitude.
2. Engage students' interest in the activity by performing several simple demonstrations that show the effects of air pressure. Possible demonstrations might include filling an empty soda can with very hot water, emptying the can, and then quickly submerging it in a container of ice water (can collapses), or filling a glass with water to the rim, placing an index card over the top of the glass, and then quickly turning it upside down (water stays inside the glass). Ask students to think about the force that can crush the can *and* keep the water inside the upside-down glass. Discuss whether this force (i.e., air pressure) is the same at all levels of the Earth's atmosphere.

Procedure

1. Distribute copies of attached Atmospheric Pressure lab sheet, and have students read through all the steps and questions for understanding. Go over any parts of the activity that need clarification.
2. Have students conduct the experiment in order to discern patterns in the Earth's atmosphere. Assist students in setting up the axes of each of the two graphs in step 7. The *y*-axis should be labeled "Altitude in kilometers" and numbered in increments of 20 km (or in increments of 100 km on every fifth line). Have students use a different colored pencil to lightly color each atmospheric layer on their graph and make a key for this shading.
3. For the <u>Altitude and Pressure Graph</u>, explain that the *x*-axis represents air pressure in millibars and will be labeled "Air Pressure (mb)." Values will range from 0.0001mb to 1,000mb. The first line on the far left of the *x*-axis will be 0.0001mb, and every fourth line will be labeled as follows: 0.001, 0.01, 0.1, 1, 10, 100, and 1,000. (Note: The data are approximate.)

4. For the Altitude and Temperature Graph, explain that the *x*-axis will be labeled "Temperature." Numbering will not be regular due to the wide range of temperatures in the atmosphere. Show students how to make a zigzag line between numbers on the *x*-axis to show compression of the numbering. Zigzags can show compression of the following ranges: −100°C to −60°C; 20°C to 200°C; and 400°C to 1,500°C. The *x*-axis range will go from −100°C on the left up to 1,750°C on the right. Have students graph the first temperature at the lowest altitude of an atmospheric layer and then the second temperature at the highest altitude of that same atmospheric layer. See the attached NASA graph for an example of what the graph will look like.
5. For both graphs, have students connect the dots to create a smooth curve (line of best fit) through the data points. The pressure graph can be turned on its side with air pressure on the right so that students can more easily visualize what happens to the pressure in each layer of the atmosphere. Likewise, the temperature graph can be turned on its side with temperature on the right so that they can more easily visualize what happens to the temperature in each layer of the atmosphere.

Assessment

- **Questions**
  - What is the relationship between altitude and air pressure? *(The higher the altitude, the lower the air pressure.)*
  - Why is air pressure less in the upper atmosphere? *(There are fewer molecules of air.)*
  - Why is air pressure greater in the lower layer of the atmosphere than the upper layers? *(There are more molecules in lower layers; 75 percent of atmospheric gases are in the troposphere.)*
  - What causes the gases to remain closer to Earth? *(Gravity; gas has mass, and anything that has mass is affected by gravity.)*
  - What is the relationship between altitude and temperature in the troposphere? *(Inverse—as the altitude increases, the temperature decreases.)*
  - Why does the temperature increase in the stratosphere? *(Because of absorption of solar radiation by the ozone layer)*
  - Which layer has the greatest range of temperatures? *(The thermosphere)*
- **Journal/Writing Prompts**
  - Explain what air pressure is.
  - Explain the relationship between altitude and pressure.
  - Explain why the air pressure is less in the upper atmosphere.
  - Explain what happens to the temperature in the troposphere as altitude increases.
- **Other**
  - Direct students to summarize what they have learned about pressure and density and about temperature and density. Allow them to can create a web, diagram, or story to demonstrate their learning.

Extensions and Connections (for all students)

- Ask students to apply what they have learned about temperature, pressure, and density to explain the phenomena observed in the opening demonstrations. For example, have them use what they learned about temperature, pressure, and density to explain why the can

collapsed in the demonstration. *(When the can was placed in the cold water, the air in the can cooled. The molecules cooled, moved together, and exerted less pressure on the can's inside walls. The greater pressure on the can's outside walls made the can collapse.)*
- Have students draw a sun at the top of the page containing their temperature graph and then draw electromagnetic waves coming down through the atmosphere. Have them show what happens to the solar radiation as it moves through the atmosphere.

Strategies for Differentiation

- For the hands-on activities, arrange students in cooperative learning groups based on learning profiles and readiness.
- Have students work in pairs or assigned groups to create graphs and answer Reflection Questions.
- Have students use graphing software to complete the activity.
- Have students use color coding on the graph to identify the layers of atmosphere.
- Show video clips related to atmospheric pressure.
- Invite a scuba diver to discuss how pressure changes with the density of water.

Atmospheric Pressure

Name: ______________________________ Date: ____________ Class: ______________________

The Effect of Pressure on Density

1. Pull the plunger out of the syringe, and then carefully reinsert it. Do not press on the plunger at this time.
   a. What makes up the air around us?

   b. What is inside the syringe?

   c. Draw a simple diagram to illustrate the contents of the syringe and another diagram of the air in the classroom.

2. Place a finger over the end of syringe, and push in plunger as far as it will go. Be careful not to allow the air in the syringe to escape.
   a. What happened to the number of air molecules inside the syringe?

   b. What happened to the amount of space the air molecules occupy?

   c. What effect did pushing in the plunger have on the density of the gas molecules inside the syringe?

   d. Draw a simple diagram to illustrate the contents of the syringe now.

3. Release your hand's pressure on the plunger and observe what happens to the volume of gas inside the syringe. Why did this occur? Describe your observations.

4. Depress the plunger about halfway. Place your finger over the end of the syringe and gently pull the plunger out as far as it will go.
   a. How would you describe the density of the gas molecules inside the syringe now?

   b. Draw a simple diagram to illustrate the contents of the syringe now.

The Effect of Temperature on Density

5. Depress the plunger about halfway, and then stopper the end of the syringe with a small piece of modeling clay. Place the syringe, plunger end up, into a hot water bath. After several minutes, record your observations below.
   a. What happened to the volume of gas inside the syringe?

   b. What can you infer about the density of the gas molecules inside the syringe when it was heated?

6. Place the same syringe into a cold water bath. After several minutes, record your observations below.
   a. What happened to the volume of gas inside the syringe?

   b. What can you infer about the density of the gas molecules inside the syringe when it was cooled?

The Effect of Altitude and Temperature on Atmospheric Pressure

7. Using data shown in the table below, do the following:
   a. Create a graph of altitude (*y*-axis) versus atmospheric pressure (*x*-axis).
   b. Create a graph of temperature (*y*-axis) versus atmospheric pressure (*x*-axis)

8. Using the graphs you have made, describe the relationship between altitude and air pressure.

9. Why is air pressure less in the upper atmosphere?

10. The pull of gravity is greatest near the surface of the Earth. How might the pull of gravity affect the density of gas molecules in the troposphere and the exosphere?

11. Describe what your graph shows with respect to altitude and temperature.

Data for Graphs

Both Graphs	Altitude and Pressure Graph	Altitude and Temperature Graph
Troposphere = 14.5 km Stratosphere = 50 km Mesosphere = 85 km Thermosphere = 500 km Exosphere = blends with outer space	0 km = 1000mb (equivalent to 14.5 pounds per square inch) 16 km = 100mb 32 km = 10mb 48 km = 1mb 64 km = 0.1mb 80 km = 0.01mb 96.6 km = 0.001mb 112 km = 0.0001mb	Troposphere = 17°C to −52°C Stratosphere = −52°C to −3°C Mesosphere = −3°C to −93°C Thermosphere = −93°C to 1,727°C Exosphere = Temperatures are very high

Atmospheric Pressure Answer Key

The Effect of Pressure on Density

1a. What makes up the air around us? *(A mixture of gases, including nitrogen, oxygen, and carbon dioxide)*

1b. What is inside the syringe? *(Air—a mixture of gases)*

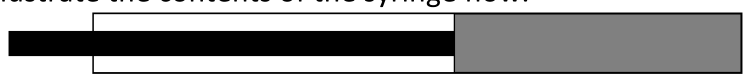
1c. Draw a simple diagram to illustrate the contents of the syringe.

2a. What happened to the number of air molecules inside the syringe? *(They stayed the same.)*

2b. What happened to the amount of space the air molecules occupy? *(It decreased.)*

2c. What effect did pushing in the plunger have on the density of the gas molecules inside the syringe? *(The density increased; there were more molecules in a smaller volume.)*

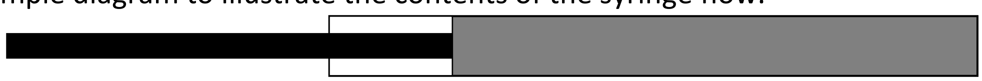
2d. Draw a simple diagram to illustrate the contents of the syringe now.



3. Why did this occur? *(The plunger moved to its original position. The pressure of the compressed gas molecules pushed the plunger back to its original position.)*

4a. How would you describe the density of the gas molecules inside the syringe? *(The density decreased; the same number of molecules now takes up a larger volume.)*

4b. Draw a simple diagram to illustrate the contents of the syringe now.



The Effect of Temperature on Density

5a. What happened to the volume of gas inside the syringe? *(The volume increased.)*

5b. What can you infer about the density of the gas molecules inside the syringe when it was heated? *(The density decreased when it was heated.)*

6a. What happened to the volume of gas inside the syringe? *(The volume decreased.)*

6b. What can you infer about the density of the gas molecules inside the syringe when it was cooled? *(The density increased when it was cooled.)*

The Effect of Altitude and Temperature on Atmospheric Pressure

7. Using the graphs you have made, describe the relationship between altitude and air pressure. *(As altitude increases, air pressure decreases.)*

8. Why is air pressure less in the upper atmosphere? *(The molecules of air are more widely spaced—i.e., the atmosphere has a lower density.)*

9. How might the pull of gravity affect the density of gas molecules in the troposphere and the exosphere? *(The pull of gravity creates a greater density of gas molecules in the troposphere, which is nearest the surface of the Earth, than it does in the exosphere, which is farthest from the surface.)*

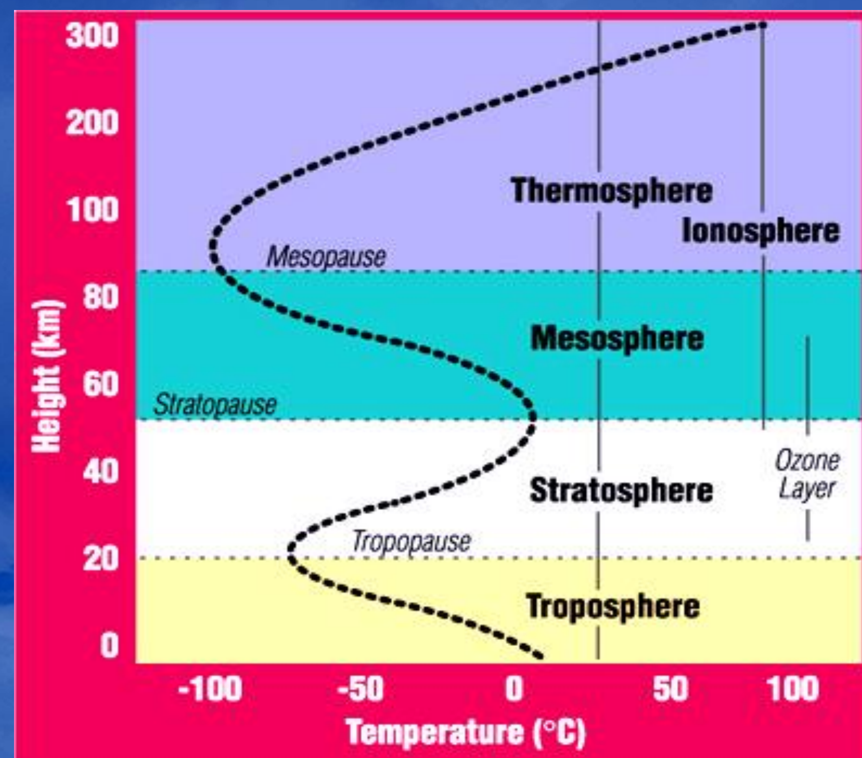
10. Describe what your graph shows with respect to altitude and temperature. *(The temperature varies throughout the layers but generally decreases from the troposphere throughout the mesosphere; then, the temperature increases.)*

Layers of the Atmosphere

Air *Our Atmosphere*

Layers of the Atmosphere

The troposphere is the lowest layer of the Earth's atmosphere, extending to a height of 8-15 kilometers (about 5-9 miles), depending on latitude. The stratosphere, warmer than the upper troposphere, is the next layer and rises to a height of about 50 kilometers (about 31 miles). Temperatures in the mesosphere, 50 to 80 kilometers (31 to 50 miles) above the Earth, decline with altitude to -70° to -140°C (-94° to -220°F), depending upon latitude and season. Temperatures increase again with altitude in the thermosphere, which begins about 80 kilometers (50 miles) above the Earth. They can rise to 2,000°C (about 3600°F). The exosphere begins at 500 to 1,000 kilometers (about 310-621 miles) and the few particles of gas there can reach 2,500°C (about 4500°F) during the day.



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