The Goldilocks Principle: A Model of Atmospheric Gases

Modified with permission from Global Climates - Past, Present, and Future*, S. Henderson, S. Holman, and L. Mortensen (Eds.). EPA Report No. EPA/600/R-93/126, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC. pp. 53 - 61.*

This activity introduces students to the atmospheric differences between the three "sister" planets in a graphic and hands-on way. They should get an overall appreciation of the important similarities and differences. Students will use this understanding later as they begin to appreciate the scope and importance of the greenhouse effect on earth.

Background

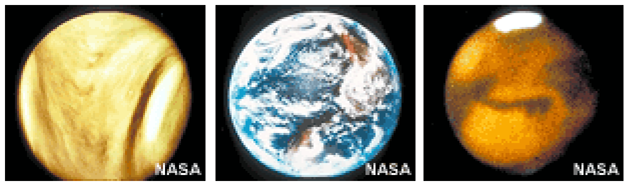
On earth, two elements, nitrogen (N_2) and oxygen (O_2), make up almost 99% of the volume of clean, dry air. Most of the remaining 1% is accounted for by the inert gaseous element, argon (Ar). Argon and the tiny percentage of remaining gases are referred to as trace gases. Certain trace atmospheric gases help to heat up our planet because they appear transparent to incoming visible (shortwave) light but act as a barrier to outgoing infrared (longwave) radiation. These special trace gases are often referred to as "**greenhouse gases**" because a scientist in the early 19th century suggested that they function much like the glass plates found on a greenhouse used for growing plants.

The earth's atmosphere is composed of gases (for example, $CO_2$and CH_4) of just the right types and in just the right amounts to warm the earth to temperatures suitable for life. The effect of the atmosphere to trap heat is the true "**greenhouse effect**."

We can evaluate the effect of greenhouse gases by comparing Earth with its nearest planetary neighbors, Venus and Mars. These planets either have too much greenhouse effect or too little to be able to sustain life as we know it. The differences between the three planets have been termed the "**Goldilocks Principle**" (Venus is too hot, Mars is too cold, but Earth is just right).

Mars and Venus have essentially the same types and percentages of gases in their atmosphere. However, they have very different atmospheric densities.

- **Venus** has an extremely dense atmosphere, so the concentration of CO_2 is responsible for a "runaway" greenhouse effect and a very high surface temperature.
- **Mars** has almost no atmosphere; therefore the amount of CO_2 is not sufficient to supply a warming effect and the surface temperatures of Mars are very low.
- **Mars is much further away from the Sun than is Venus.**



	Venus	Earth	Mars
Carbon Dioxide (CO_2)	96.5%	0.03%	95%
Nitrogen (N_2)	3.5%	78%	2.7%
Oxygen (O_2)	Trace	21%	0.13%
Argon (Ar)	0.007%	0.9%	1.6%
Methane (CH_4)	0	0.002%	0

Earth has a very different type of atmosphere. Our atmosphere has much less CO_2 than Venus or Mars and our atmospheric pressure is close to midway between the two (1/90th that of Venus and 100 times that of Mars).

Many scientists believe that the composition of our atmosphere is due to the presence of life. Life acts to keep Earth's atmosphere in a dynamic balance. In other words, if life were to completely disappear, eventually our atmospheric composition could come to closely resemble Mars or Venus. Only with life continually producing oxygen through photosynthesis and removing and re-circulating CO_2 does Earth's atmosphere remain fairly stable.

This activity introduces students to the atmospheric differences between the three "sister" planets in a graphic and hands-on way. Students need not memorize the chemical compositions and pressures of the three atmospheres; rather, the activity should give them an overall appreciation of the important similarities and differences. Students will use this understanding later as they begin to appreciate the scope and importance of the greenhouse effect on earth and realize that rather than being a bad thing, the greenhouse effect is critical for the survival of the biosphere.

Learning Goals

1. Students will understand that our two closest neighbors, Venus and Mars, have very different atmospheres than Earth does in pressure and chemical composition.

2. Students will be able to explain the "Goldilocks Principle" and understand that Earth's moderate temperature is due primarily to its unique atmosphere.

Alignment to National Standards

National Science Education Standards

- Unifying Concepts and Processes, Grades K to 12, pg.117: "Models are tentative schemes or structures that correspond to real objects, events, or classes of events and that have explanatory power."

- Earth and Space Science, Grades 5 to 8, pg.160, Earth in the Solar System, Item #1: "The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system."

- Earth and Space Science, Grades 5 to 8, pg.160, Structure of the Earth System, Item #8: "The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has different properties at different elevations."

Benchmarks for Science Literacy, Project 2061, AAAS

- Common Themes, Models, Grades 6 to 8, pg. 269, Item #1: "Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous."

- The Earth, Grades 6 to 8, pg. 68-9, Item #2: "The earth is mostly rock. Three-fourths of its surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin blanket of air. It is the only body in the solar system that appears able to support life. The other planets have compositions and conditions very different from the earth's."

Grade Level/Time

- **Grade level:** 6 to 9 (Note: Younger grades might enjoy the model construction but may have difficulty translating the abstract model into an understanding of the real atmospheres.)
- **Time**
    - Teacher's introduction and instructions: 30 minutes
    - Student model-building: 30 minutes
    - Discussion/assessment: 30 minutes

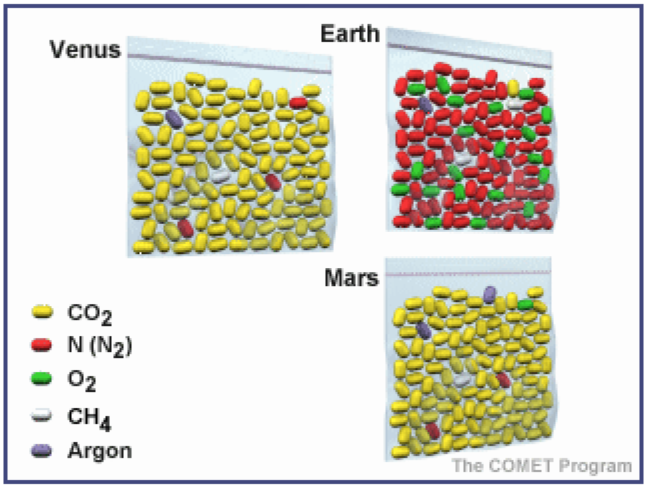
Materials

- Colored cotton balls, jellybeans, or different colored beans (or similar materials) to represent gases in the atmosphere
- Re-sealable plastic bags

Procedure

1. Discuss the "Goldilocks Principle." Use the information in Tables 1 and 2 to engage the class in a discussion of the greenhouse effect. If available, you may want to share illustrations or slides of Mars, Venus, and Earth.
2. After discussing the atmospheres of Earth and the other planets, ask the students (in teams or pairs) to build models of the atmospheres of Earth and the other planets. Emphasize that models are critical tools for planetary scientists trying to understand phenomena too distant to experience directly.
3. Depending on the material available, ask students to represent the atmospheric gases with different colored beans, cotton balls, or jelly beans. (We will use jellybeans for examples in this activity.) They might represent:
    - Nitrogen (N_2) with red jellybeans
    - Oxygen (O_2) with green jellybeans
    - Argon (Ar) with purple jellybeans
    - Carbon dioxide (CO_2) with yellow jellybeans
    - Methane (CH_4) with white jellybeans

Representing atmospheric density with jellybeans is impractical – if Earth's atmosphere has 100 jellybeans, Venus will have 9,000, and Mars will have slightly more than 1/2 jellybean (0.6). Suggest that the students use 10 or 100 as the base number for each planet. Let the students know what the real differences in density are.



4. Challenge the students to produce a model atmosphere for each planet by placing the appropriate number of jellybeans in three small, re-sealable plastic bags. The necessary information is provided in Table 2. They will have to translate percentages into numbers of jellybeans, and in many cases, will face the difficulty of cutting the jellybeans into small enough pieces to represent small atmospheric concentrations.

5. Have students explain what they found to the class.

6. To extend this activity, you could take one set of bags and distribute the contents in areas measured to represent atmospheric pressure of each planet. For example, the jellybeans representing Earth might be distributed in a meter square. You might have to go outside to find an area big enough to represent the thin atmosphere found on Mars. To concentrate the beans representing the dense atmosphere of Venus, you could use a food processor or mortar and pestle to concentrate the jellybeans.

Assessment Ideas

1. Have the students display their work in the classroom and allow time for them to observe and discuss each other's work as you circulate.

2. Have students respond in writing to the following questions:

- Describe the atmospheric conditions you might encounter as an astronaut setting foot on Venus and Mars.
- Name at least two ways that the atmospheres of Venus and Mars are similar to each other, and one way that both differ from Earth's.
- What new information did you learn in this lesson? What did you already know? What was the hardest thing about the activity?

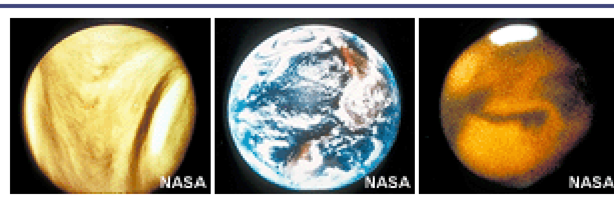
Modifications for Alternative Learners

1. Students who have difficulty with math concepts should be paired with students strong in math to avoid frustration with the fractions.
2. Students with language difficulty should be assisted directly at the beginning of the model building to make sure they understand the instructions.

Additional Resources

Table 1

The table below lists the atmospheric factors responsible for the planetary differences. The relative distance from the Sun has some influence on planetary temperature, but the greenhouse gases and atmospheric density have more of an impact on temperature. Venus has an extremely dense atmosphere (with a surface pressure 90 times that relative to Earth's). Conversely, Mars has an extremely thin atmosphere (with a surface pressure less than 1/100th of that relative to Earth's).

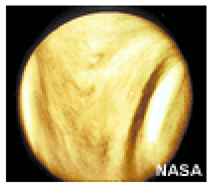


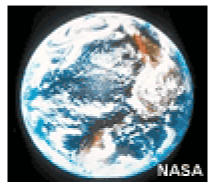
	Venus	Earth	Mars
Surface pressure relative to Earth (bars)	90	1	0.007
Major greenhouse gases (GHG)	CO_2	H_2O, CO_2	CO_2
Temperature if no GHG (°C)	-46	-18	-57
Actual temperature (°C)	477	15	-47
Temperature change due to GHG	+523	+33	+10

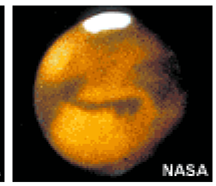
Table 2

The chemical composition of the atmospheres are important (at least to the presence of life). The major greenhouse gases (GHG) and their percentages are listed below.

Note: In the Earth's dry atmosphere, nitrogen and oxygen comprise almost 99% of the gases. The remaining trace gases (with the exception of water vapor), add up to less than 1% of gases found in Earth's atmosphere. The amounts on the table below do not add up to exactly 100% because not all of the trace gases have been included. The table below includes only the principal gases found in the Earth's dry air. Water vapor, an important greenhouse gas, is not addressed in this activity.







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When you're finished with the activity, click on To Student Guide or Back to Activities List at the top of the page to return to the activity menu.

Back to Top