HW 9

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Astronomy 138 - Dr. Matthew Duez
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Gas retention simulator

Ref: Gas retention simulator (authored by the Columbia Center for New Media Teaching and Learning; Columbia University; hosted on github)

https://ccnmtl.github.io/astro-simulations/gas-retention-simulator/

Ref: NASA Planetary fact sheet - metric

https://nssdc.gsfc.nasa.gov/planetary/factsheet/index.html

In this exercise we will simulate planetary atmospheres: their composition, temperature, and escape conditions.

In your favorite browser, navigate to the simulation and spend a few minutes playing with the controls. Orient yourself to the display: the box on the upper left is a chamber in which a gas will be contained; the gas particles (atoms or molecules) are represented by little colored balls that move about, and the shade (darker or lighter) of color of each ball indicates how quickly it is moving. The display at upper right shows a histogram of the number of gas particles at a particular speed at any instant.

When you are ready, **Reset** the simulation (top right).

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1. Pull down the menu entitled **Select gases to add** and select Xenon. Leave the other settings at their default values. Then select **Start simulation.** Focus upon a single gas atom and follow it for several seconds. Does it always move at the same speed? If not, what causes its speed to change?

No, when the atom collides with another it changes speed.

2. Look at the distribution plot. In the previous question we established that a given particle speeds up and slows down. Why does the distribution plot NOT change over time?

When one particle speeds up, another slows down so the distribution of the speed of all particles never changes.

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3. **Reset** the simulation. Now simulate the atmosphere of Earth as it was 4.5 billion years ago. Add three gases: hydrogen, water, and carbon dioxide. Set the temperature to 288 kelvin (from the NASA fact sheet, Earth's mean T = 15 C; 15 Celsius + 273 = 288 kelvin). Check on the box beside **Allow escape from chamber**. Set the escape speed to 1/8 of Earth's escape speed, 11.2/8 = 1.4 km/s = 1400 m/s. Start the simulation and wait at least 60 seconds. Which gases escape? Which are retained? Do your results verify what you expected; if so then how, and if not then how not?

Hydrogen escapes, carbon dioxide and water are retained. This matches what we expect, as the lighter molecule (hydrogen) which has a higher average molecular speed escapes more frequently then the slower, bigger molecules (water and carbon dioxide).

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4. **Reset** the simulation. Now simulate Mars: record here Mars's mean temperature (kelvin) and 1/8 escape speed (m/s). Add hydrogen, water, and carbon dioxide to the chamber. Start the simulation and wait at least 60 seconds. Does the end result resemble the composition of Mars's atmosphere today?

$-65C = 208.15K$
$(5\text{km/s})/8 = 625\text{m}/s$
Yes, there is a huge proportion of carbon dioxide and much less of every other element.

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5. Reset the simulation. Now simulate Venus. Record your initial conditions. Record your results. Write a sentence or two of interpretation of your results.

$464C = 737.15K$
$(10.4\text{km/s})/8 = 1300\text{m}/s$

Most of the hydrogen escaped, with water also dwindling in amount on Venus. Carbon dioxide remains in the highest proportion, as it is the heaviest molecule out of them all.

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6. Generalize your results: under what conditions will a gas escape from a planet's atmosphere? Under what conditions will a gas be retained in a planet's atmosphere?

If the molecules average speed distribution largely remains under the escape velocity of the planet's atmosphere, it will likely retain. On the contrary, if its higher than the escape velocity on average, it will likely leave.

Citations

Gas retention simulator. Accessed April 7, 2025. https://ccnmtl.github.io/astro-simulations/gas-retention-simulator/.

“Planetary Fact Sheet.” NASA. Accessed April 7, 2025. https://nssdc.gsfc.nasa.gov/planetary/factsheet/index.html.
