# Atmospheric Retention

## 

## A. How fast must you move to escape a planet?

You will be using the NAAP Atmospheric Retention simulations.

Open the Projectile Motion Simulator.

1. Experiment with the initial speed until you zero in on the smallest value for which the projectile goes up and never returns to the Earth. What value do you get?

2. Now using that as a starting point, experiment to see how the planet mass and planet radius affect the escape velocity.

3. Now open the NAAP Escape Velocity component. This is a brief explanation of escape velocity and what it depends on. Is it consistent with your results from above?

4. Imagine that asteroid Alpha has an escape velocity of 50 m/s. If asteroid Beta has twice the mass and twice the radius, it would have an escape velocity \_\_\_\_\_\_\_\_\_\_\_\_\_\_ the escape velocity of asteroid A. Choose one to fill the blank. Explain your reasoning.

5. Fill in the table below using what you have learned about escape velocity. Open the program Projectile Motion Simulator again and check your results. Since the masses and radii are given in terms of the Earth’s (vesc = 11.2 km/s), you can easily check your values by using the mathematical formula for escape velocity.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Object** | **Mass (in Earth masses)** | **Radius (in Earth radii)** | **Measured vesc (in km/s)** | **Calculated vesc (in km/s)** |
| Mercury | 0.055 | 0.38 |  | 4.3 |
| Uranus | 15 | 4.0 |  |  |
| Io | 0.015 | 0.30 |  |  |
| Vesta | 0.00005 | 0.083 |  |  |
| Mars | 0.107 | 0.532 |  |  |
| Jupiter | 317.8 | 11.209 |  |  |
| Krypton1 | 100 | 10 |  |  |

1 Source: Action Comics #1, 1938.

***Discuss your results with the Instructor at this point***

## B. Temperature and gas speed

1. Open the Gas Retention Simulator. Choose a gas from the list and experiment with it. The graph shows how many gas particles are moving at each velocity. In the box, they are coded according to darker = slower. Then

1. Draw a sketch of a typical gas curve below with axes labeled appropriately. This is called a Maxwell Distribution after the guy who first calculated it. It is almost a bell curve but not quite.
2. Show the point on the curve where the largest number of particles have the same velocity. This is called the most probable velocity, vmp.
3. Click the box Show Draggable Cursor and find the average velocity. vavg. Indicate it on your graph.
4. Are vavg and vmp the same value? Use the shape of the graph to explain your answer.

2. Try the other gases. The mass of each gas particle is in the box below the pick list. For instance, carbon dioxide has a mass of 44u where an atomic mass unit, u, is the mass of a hydrogen atom. So carbon dioxide is 44 times heavier than hydrogen. Record your results. What happens to the graph and to the two critical velocities as you vary the gas?

***Discuss your results with the Instructor at this point***

3. Use the pull-down menu to add helium to the chamber.

Complete the table using the draggable cursor to measure the most probable velocity for helium at each of the given temperatures. Write a short description of the relationship between T and vmp.

|  |  |
| --- | --- |
| **T (K)** | **vmp (m/s)** |
| 700 |  |
| 500 |  |
| 300 |  |
| 200 |  |
| 100 |  |

4. If the simulator allowed the temperature to be reduced to 0 K, what would you guess would be the most probable velocity at this temperature? Why?

5. Return the temperature to 300 K. Use the gas panel to add Ammonia and Carbon Dioxide to the chamber in addition to hydrogen. Complete the table using the draggable cursor to measure the most probable velocity at a temperature of 300 K and recording the atomic mass for each gas. Write a short description of the relationship between mass and vmp and the width of the Maxwell distribution.

|  |  |  |
| --- | --- | --- |
| **Gas** | **Mass (u)** | **vmp (m/s)** |
| H2 |  |  |
| NH3 |  |  |
| CO2 |  |  |

6. Check the box entitled allow escape from chamber in the chamber properties panel. You should still have an evenly balanced mixture of hydrogen, ammonia, and carbon dioxide. Run each of the simulations specified in the table below for the mixture. Click reset proportions to restore the original gas levels. Write a description of the results similar to the example completed for you.

|  |  |  |  |
| --- | --- | --- | --- |
| **Run** | **T (K)** | **vesc (m/s)** | **Description of Simulation** |
| 1 | 500 | 1500 | H2 is very quickly lost since it only has a mass of 2u and its most probable velocity is greater than the escape velocity, NH3 is slowly lost since it is a medium mass gas (18u) and a significant fraction of its velocity distribution is greater than 1500 m/s, CO2 is unaffected since its most probable velocity is far less than the escape velocity. |
| 2 | 500 | 1000 |  |
| 3 | 500 | 500 |  |
| 4 | 100 | 1500 |  |
| 5 | 100 | 1000 |  |
| 6 | 100 | 500 |  |

7. Write a summary of the results contained in the table above. Under what circumstances was a gas likely to be retained? Under what circumstances is a gas likely to escape the chamber?

***Discuss your results with the Instructor at this point***

## C. Gas Retention Plot

Open the program gasRetentionPlot. This simulator presents an interactive plot summarizing the interplay between escape velocities of large bodies in our solar system and the Maxwell distribution for common gases. The plot has velocity on the y-axis and temperature on the x-axis. Two types of plotting are possible:

* A point on the graph represents a large body with that particular escape velocity and outer atmosphere temperature. An active (red) point can be dragged or controlled with sliders. Realize that the escape velocity of a body depends on both the density (or mass) and the radius of an object.
* A line on the graph represents 10 times the average velocity (10×vavg) for a particular gas and its variation with temperature. This region is shaded with a unique color for each gas.
  + If a body has an escape velocity vesc over 10×vavg of a gas, it will certainly retain that gas over time intervals on the order of the age of our solar system.
  + If vesc is roughly 5 to 9 times vavg, the gas will be partially retained and the color fades into white over this parameter range.
  + If vesc < 5 vavg, the gas will escape into space quickly.

1. Begin experimenting with all boxes unchecked in both the gasses and plot options. Plot the retention curves for the gases hydrogen, helium, ammonia, nitrogen, carbon dioxide, and xenon. Explain the appearance of these curves on the retention plot.

2. Check “show gas giants” in the plot options panel. Discuss the capability of our solar system’s gas giants to retain particular gases among those shown.

3. Drag the active point to the location (comparable with the escape speed and temperature) of Mercury. The gases hydrogen, helium, methane, ammonia, nitrogen, and carbon dioxide were common in the early solar system. Which of these gases would Mercury be able to retain?

4. Most nitrogen atoms have a mass of 14u (hence 28u for N2), but a small percentage of nitrogen atoms have an extra neutron and thus an atomic mass of 15u. (We refer to atoms of the same element but with different masses as isotopes of that element.) Recently, scientists studying isotope data from the Cassini spacecraft have noticed that the ratio of 15u nitrogen to 14u nitrogen is much larger than it is here on earth. Assuming that Titan and the earth originally had the same isotope ratios, explain why the ratios might be different today.

5. Other observations by the Cassini probe have confirmed that Titan has a thick atmosphere of nitrogen and methane with a density of about 10 times that of the Earth’s atmosphere. Is this finding completely consistent with Titan’s position on the atmospheric retention plot? Explain. (Make sure that show icy bodies and moons is checked as well as the gasses methane and nitrogen.)

***Discuss your results with the Instructor***

***Questions***

1. Elon Musk thinks we should terraform and colonize Mars. To do that, a substantial change has to be made to the Martian atmosphere. It must be made much thicker and contain a substantial amount of nitrogen, oxygen and water. Considering what you have learned from this activity, how would you assess that plan. Is it likely to be successful?

2. Earth used to have a lot of CO2 in its atmosphere, similar to Venus. Earth is just far enough from the Sun for liquid water to exist on the surface and CO2 dissolves very easily in water. That’s how you get fizzy drinks. That CO2 is used by aquatic microorganisms to make calcium carbonate (CaCO3) protective shells. When they die, they sink to the bottom and over time become limestone. That process gradually removes CO­2 from the atmosphere. Venus is too hot for liquid water to exist. Water vapor eventually circulates to the upper atmosphere where solar ultraviolet radiation blasts it apart into hydrogen and oxygen. Given that they formed in similar parts of the solar system, Venus and Earth should have started with similar amounts of water. But in contrast to Earth, Venus has essentially no water. Can you explain why?