

Atmospheric Retention – Student Guide

Background Information

Work through the background sections on Escape Velocity, Projectile Simulation, and Speed Distribution. Then complete the following questions related to the background information.

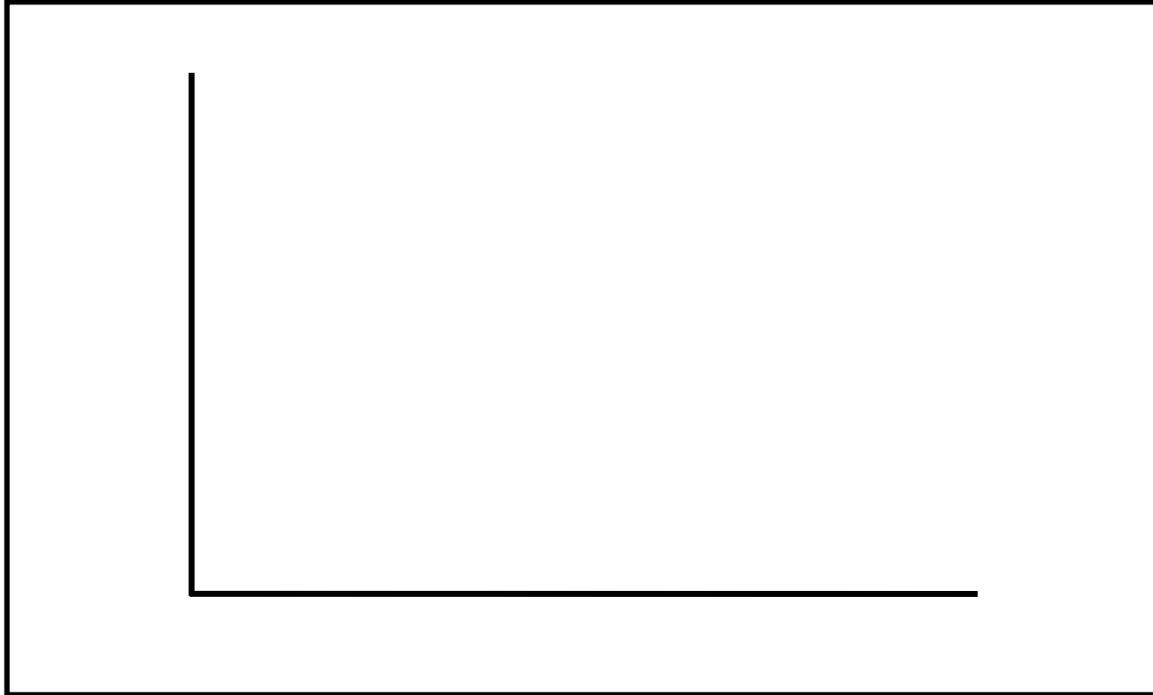
Question 1: Imagine that asteroid A that has an escape velocity of 50 m/s. If asteroid B has twice the mass and twice the radius, it would have an escape velocity _____ the escape velocity of asteroid A.

- a) 4 times
- b) Twice
- c) the same as
- d) half
- e) one-fourth

Question 2: Complete the table below by using the Projectile Simulator to determine the escape velocities for the following objects. Since the masses and radii are given in terms of the Earth's, you can easily check your values by using the mathematical formula for escape velocity.

Object	Mass (Mearth)	Radius (Rearth)	v _{esc} (km/s)	v _{esc} (km/s) calculation (optional)
Mercury	0.055	0.38		$\sqrt{\frac{(0.055)}{(0.38)}} \left(11.2 \frac{km}{s} \right) = 4.3 \frac{km}{s}$
Uranus	15	4.0		
Io	0.015	0.30		
Vesta	0.00005	0.083		
Krypton	100	10		

Question 3: Experiment with the Maxwell Distribution Simulator. Then a) draw a sketch of a typical gas curve below, b) label both the x-axis and y-axis appropriately, c) draw in the estimated locations of the most probable velocity v_{mp} and average velocity v_{avg} , and d) shade in the region corresponding to the fastest moving 3% of the gas particles.



Maxwell Speed Distribution

Gas Retention Simulator

Open the **gas retention simulator**. Begin by familiarizing yourself with the capabilities of the gas retention simulator through experimentation.

- The **gas retention simulator** provides you with a **chamber** in which you can place various gases and control the temperature. The dots moving inside this chamber should be thought of as tracers where each represents a large number of gas particles. The walls of the chamber can be configured to be a) impermeable so that they always rebound the gas particles, and b) sufficiently penetrable so that particles that hit the wall with velocity over some threshold can escape. You can also view the distributions of speeds for each gas in relation to the escape velocity in the **Distribution Plot** panel.
- The lower right panel entitled **gases** allows you to add and remove gases in the experimental chamber. The lower left panel is entitled **chamber properties**. In its default mode it has **allow escape from chamber** unchecked and has a **temperature** of 300 K. Click **start simulation** to set the particles in motion in the chamber panel. Note that **stop simulation** must be clicked to change the temperature or the gases in the simulation.
- The upper right panel entitled distribution plot allows one to view the Maxwell distribution of the gas as was possible in the background pages. Usage of the show draggable cursor is straightforward and allows one to conveniently read off distribution values such as the most probable velocity. The show distribution info for selected gases requires that a gas be selected in the gas panel. This functionality anticipates a time when more than one gas will be added to the chamber.

Exercises

- Use the pull-down menu to add hydrogen to the chamber.

Question 4: Complete the table using the draggable cursor to measure the most probable velocity for hydrogen at each of the given temperatures. Write a short description of the relationship between T and v_{mp} .

T (K)	v_{mp} (m/s)
300	
200	
100	

Question 5: 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? _____

- Return the temperature to 300 K. Use the gas panel to add Ammonia and Carbon Dioxide to the chamber.

Question 6: 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 v_{mp} and the width of the Maxwell distribution. _____

Gas	Mass (u)	v_{mp} (m/s)
H2		
NH3		
CO2		

Question 7: 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)	v_{esc} (m/s)	Description of Simulation
1	500	1500	H ₂ is very quickly lost since it only has a mass of 2u and its most probable velocity is greater than the escape velocity, NH ₃ 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, CO ₂ 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	

Question 8: 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? _____

Gas Retention Plot

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 ($10 \times v_{\text{avg}}$) 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 v_{esc} over $10 \times v_{\text{avg}}$ of a gas, it will certainly retain that gas over time intervals on the order of the age of our solar system.
 - If v_{esc} is roughly 5 to 9 times v_{avg} , the gas will be partially retained and the color fades into white over this parameter range.
 - If $v_{\text{esc}} < 5 v_{\text{avg}}$, the gas will escape into space quickly.

Exercises

- Begin experimenting with all boxes unchecked in both the gasses and plot options.

Question 9: 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. _

- Check show gas giants in the plot options panel.

Question 10: Discuss the capability of our solar system's gas giants to retain particular gases among those shown. _____

Question 11: 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? _____

Question 12: 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. _____

Question 13: 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.) _____

