# Atmospheres, Escape of Gas, and the Evolution of the Atmosphere of Mars – Instructor’s Guide

### Part 1: Atmospheric Gas

Gas particles in this box move randomly; the arrows show the direction and size of particle movements. The combined motion of the particles colliding with each other (and the box) is felt as the **pressure** of the gas.

1. What happens to the particle movements as you increase the temperature of the gas?

***Particles should move faster as temperatures increase.***

2. What effect will that temperature increase have on the pressure of the gas?

***Since particles move faster due to the temperature increase, they will collide with each other and the box more often, which is felt as an increase in the gas pressure.***

3. If you now increase the volume of the box (decreasing the density of particles), what effect will that have on the pressure of the gas?

***If you decrease the density of particles, they will collide with each other and the box less often, which is felt as a decrease in the gas pressure.***

Now suppose you have a significant amount of gas surrounding a planet (an atmosphere). Notice that in this case there is no “box” or container keeping the particles confined.



4. What keeps the gas particles from flying away into space?

***The planet’s gravity attracts the gas toward the surface.***

5. What keeps all of the gas particles from collapsing to the surface of the planet?

***The pressure of the atmosphere keeps the gas from collapsing down to a very thin surface layer. That pressure will rise as you go closer to the surface, since the mass of the gas above pushes down on the gas below.***

6. Suppose you raise the temperature at the surface of the planet. What effect will that have on the motions of particles in that planet’s atmosphere?

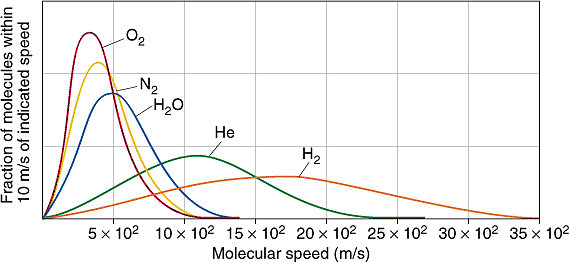
***Particles in the atmosphere should move faster as you raise the temperature (leading to an increase in atmospheric pressure).***

7. Given your answer to Question 6, and the fact that there is no “container” for the atmosphere, what do you think will be the overall consequence of raising the temperature on the atmosphere of the planet?

***The faster particle motions should lead to an increase in atmospheric pressure. Since there is no container, the gas should push against itself and the surface, expanding the atmosphere.***

### Part 2: Particle Speeds and Escape Velocity in an Atmosphere

We have established that at higher temperatures, gas particles (atoms and molecules) in an atmosphere will move at higher speeds. The speeds that the particles will reach also partly depend on the **mass** of the particles.

**

*Figure 1: The chart above shows the distribution of speeds of some atmospheric atoms and molecules at a constant temperature of 298.15 K (25° C). (Source: Chemistry LibreTexts,* [*https://chem.libretexts.org/*](https://chem.libretexts.org/)*, UC Davis Chemistry Chemistry 107A)*

Notice that in Figure 1, each particle has a peak at the “most probable speed” for a given atom or molecule. Hydrogen and helium, the lightest gases, have the highest speeds at a given temperature. We can calculate this most probable speed mathematically, using the formula, . In this formula, *k* is Boltzmann’s constant, *k*=1.38x10-23 m2 kg s-2 K-1, *T* is the temperature in Kelvin, and *mparticle* is the mass per particle (atom or molecule) in kg.

8. Using the graph and the formula given above, what kind of particles will reach the highest most-probable speeds?

***The lightest particles (those with the smallest mparticle) reach the highest speeds. From the graph in Figure 1, that would be first hydrogen, then helium.***

9. Is there a point at which the speed of the particle will be higher than the forces that hold the molecules around the planet? What is our name for that speed?

***The speed where a particle moves faster than the forces holding the particle to the planet is known as the escape velocity. (Technically, this is the speed where the particle’s kinetic energy is greater than the planet’s gravitational potential energy.)***

10. Notice that even if the peak speed is not very high, there is a wide range of particle speeds above the most-probable speed. Do you think some of these fast-moving particles might be able to escape from the planet? Why or why not?

***Yes, if some of the particles are moving faster than escape velocity, they should be able to escape the planet’s gravity and fly away into the solar system.***

In general, if the most probable speed is at least 20% of the escape velocity, fast-moving particles will have a chance to “leak away” from a planet’s atmosphere over the lifetime of the planet to date.

11. Based on Figure 1, which gases are most likely to escape from a planet’s atmosphere over its lifetime?

***From the graph in Figure 1, hydrogen and helium particles are most likely to reach escape velocity and thus escape from the atmosphere over long periods of time.***

12. How will the escape velocity of a planet with a higher mass be different from the escape velocity of a planet with a lower mass? (Hint: Think about how mass affects the force of gravity.)

***A planet with a higher mass has more gravitational force on the particles, and thus will have a higher escape velocity. A planet with lower mass will have a lower escape velocity.***

13. What does your answer to question 12 tell you about which planets are more likely to lose gases from their atmospheres over time?

***From question 12, planets with lower masses have lower escape velocities. From Figure 1 and questions 9-10, these planets are more likely to lose gases from their atmospheres, with the lightest gases escaping first.***

### Part 3: Applying These Principles to the Atmosphere of Mars

14. Is Mars a comparatively large planet, or is it relatively small compared to other planets of the Solar System? Is it likely to have a high or low escape velocity?

***Mars has the second-lowest mass among the planets of the Solar System. As such, it is likely to have a low escape velocity compared to the other planets.***

15. Is Mars likely to have experienced a significant loss of gases from its atmosphere over time, compared to other planets of the Solar System?

***Because of the low escape velocity, as discussed in question 13, low-mass Mars is far more likely than most other planets to have lost significant amounts of atmospheric gas.***

Early in the history of Mars, it had an active geology, including many volcanoes, some of which are still visible (although probably not active) today. Martian volcanoes, when active, released quantities of new gas like carbon dioxide into the atmosphere, a process called “outgassing.”

16. How do you think these two factors – outgassing from volcanoes, and any loss of gases which exceeded the escape velocity of Mars – would affect the balance of the Martian atmosphere?

***Outgassing will add more particles into the Martian atmosphere, while gases reaching escape veolocity will subtract particles. While it depends on the rate of loss and gain of gas, the outgassing at least will slow down the loss of atmosphere from Mars.***

17. Over time, Mars cooled, and its geology became less and less active. Volcanism more or less shut down. Once volcanoes were no longer outgassing, what do you think would happen to the atmosphere of Mars?

***Without the mitigating supply of particles from outgassing volcanoes, particles lost from Mars’ atmosphere will not be replaced. This will make the net loss of gas from the atmosphere more severe over time.***

18. The fact that Mars had an active geology early in its history implies that it may also have had a significant magnetic field (due to molten iron in its core). This would have protected the atmosphere of Mars from having gas stripped away by interactions with the solar wind. Would this protection have continued up to the present, when Mars has lost almost all of its active geology?

***If there were no active geology, there would be no molten core, and thus no magnetic field protecting the Martian atmosphere from the solar wind.***

19. Based on your answer to the previous two question and question 3, what do you think has happened to the pressure in the Martian atmosphere over time?

***The Martian atmosphere is likely to have been losing gas over time (after the geology became inactive), some due to particles reaching escape velocities without replacement from outgassing, and some due to interaction of the particles with the solar wind stripping those particles from the atmosphere.***

20. As Mars lost the heat that powered its previously active geology, what would have happened to the temperatures at the Martian surface?

***Without the internal heat of the planet, the temperature of the surface would likely go down.***

21. Water requires a specific range of surface temperatures and atmospheric pressures to be present in liquid form on a planet’s surface We have evidence that in the past, there was liquid water on the surface of Mars. Would you expect that liquid water to still be present? Why or why not?

***With substantially lower atmospheric pressures due to the loss of gas, there would likely not be enough pressure to keep water liquid at Mars’ surface. Also, with colder surface temperatures, water would be more likely to freeze into solid form.***