Student Guide - Scale Height

Background Information

1. Complete the following table with numerical and algebraic values for atmospheric density at various heights above the surface of a terrestrial body.

Height	Algebraic Expression	Density Value
z=1.00 H	$\rho = \rho_0 e^{-\frac{1}{H}}$	0.368
z=2.00 H		
	$\rho = \rho_0 e^{\frac{-2.5}{H}}$	
		0.183
z=6.00 H		
		0.00166

2. Scale Height is defined as $H=\frac{kT}{\mu m_H g}$ where k = 1.38 x 10⁻²³ J/K. Perform dimensional analysis and determine the units of scale height.

Atmospheric Simulators

3. The height $h_{\frac{1}{2}}$ is defined as the altitude where the density (or pressure) is half its value at the surface. Solve algebraically for the value of $h_{\frac{1}{2}}$ (and then check your value in the simulator).

4. The scale height, atmospheric surface density (in terms of Earth's atmospheric surface density), and maximum elevation for Venus, Earth, and Mars are given in the table below. Use scale height to calculate the atmospheric density at the maximum elevation for each body (in terms of Earth's surface density).

Body	Surface Atm Density (ρ ₀)	Maximum Altitude (km)	Algebraic Expression and Value
Venus	93ρ ₀	11	
Earth	ρο	8.9	
Mars	0.0064ρ ₀	22	

5.	a) At what altitude (in units of both km and scale height) does Earth's atmospheric density fall to 1/10 its
	initial value?

b) What is the pressure at the cruising altitude of most airplanes (approximately 10 km)?

c) The summits of Earth's tallest mountains (notably Mount Everest) lie within the "Death Zone"—the elevations at which atmospheric pressure is too low for humans to survive for extended periods. The pressure at the beginning of the "death zone" is 356 millibars, or 35.6 kPa. At what altitude does this occur, in units of km and scale height?

6.	Given the scale height H, radius R, acceleration of gravity g, and the density of the atmosphere at sea level ρ_0 for Earth, identity an algebraic expression and calculate its value for the total mass of Earth's atmosphere.
7.	a) Find the scale height for the planet Venus if its atmosphere was 100% H_2 .
b) I	Find the scale height for the planet Venus if its atmosphere was 100% CH ₄ .
c)	Find the scale height for the planet Venus if its atmosphere was 50% H_2 and 50% CH_4 .
	How accurate do you believe your answer to part c) to be? Explain. (Hint: You might find some help on the nerical cow page.)
8.	Earth's primordial atmosphere is thought to be very similar to the atmosphere of Titan today. Use the second simulator to determine the scale height of the atmosphere on the very early Earth. Give the value and provide a short description of the process. How does Earth's primordial atmosphere differ from the atmosphere on Titan today?

Meteoroid Impacts

- 9. On February 15, 2013, a meteoroid disintegrated in the atmosphere over Chelyabinsk, Russia. The energy released produced window-breaking shockwaves, intense heat, and numerous small fragments of the original meteoroid. These effects combined to injure more than 1500 people. (The meteor's explosion was well-documented; going to YouTube and searching "Chelyabinsk meteor" will produce several results.) The meteor gained significant media attention, in part because of how visually impressive and damaging it was, but also because it caught everyone by surprise. Although astronomers attempt to track large near-Earth objects which could potentially become damaging meteoroids, the Chelyabinsk meteor was not detected prior to its atmospheric entry.

 Because the meteor was destroyed in the atmosphere, attaching numbers to it is difficult; the best estimates of its mass and diameter are 10⁷ kg and 20 meters, respectively.
- a) Using these values, calculate the density of the Chelyabinsk meteor. Assume a spherical shape.
- b) What does this value tell us about the meteor's composition—was it likely to be metallic, rocky, or icy?

- c) Input these values into the meteor impact simulator. If we had known of the meteor's existence before it entered the atmosphere, what would we have predicted its fate to be? How confident could we be in this prediction? Does this prediction line up with the meteor's actual fate—atmospheric disintegration very near Earth's surface?
- d) Suppose a new meteor had the same mass as the Chelyabinsk meteor (10⁷ kg) but was twice as dense. Calculate the new meteor's radius and input these values into the simulator. Is the new meteor more likely or less likely to survive to Earth's surface?

10. a) A spherical stone (ρ_M =3 g/cm³) meteorite of radius R_M = 0.5 m heads toward Earth at high velocity. What do you think is the likely outcome? Explain why?
b)) An identical stone (with the same kinematics) heads toward Mars. What do you think is the likely outcome? Explain why?
c) An identical stone (with the same kinematics) heads toward Venus. What do you think is the likely outcome? Explain why?

11. Suppose you are part of a group of scientists in year 2100 tasked with finding a suitable planet for human habitation. You are considering an Earthlike planet with mass 2.2 M_E , radius 1.3 R_E , and surface temperature 300 K.
a) What is the scale height of the planet's atmosphere if the atmosphere is composed of 50% Ar, 30% O_2 , and $20\%~N_2$?
b) The solar system in which the planet resides is full of small cometary bodies and debris, leading some members of your group to be concerned about planetary impacts. You have determined that the debris is no larger than 50 m in radius, and that all of it is rocky (density ~5 km). If the planet's atmosphere has a surface density of 2.8 kg/m³, would the planet be safe from impacts?