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Astronomy 103H Honors Project

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Scale Height Lab Review

Lab Review (Areas of Improvement)

1. **Background Pages**

Three informational background pages are included in this lab. These include the Definition of Scale Height, Meteor Impact Background, and Spherical Cow Issues. The first of these pages is the most relevant to questions 1-8 of the exercises. After reading this background page and completing the exercises relating to it, I have a few suggestions on how to make it more readable. One part of the lab that was difficult for me was the calculations portion due to my relatively small background in the physics and astronomy fields. So, for students that also may struggle with this, I would suggest making a table with the formulas used and their variables. This will also help the organization throughout the background pages. Organizing information into a table would be less overwhelming than the current organization, in my opinion. Another suggestion I have on the first background page is the conciseness of the wording. A few sentences were not hitting the meaning of the sentence spot-on, even though they were not vague enough to the point of not understanding.

The second background page, Meteoroid Impact Background, followed the exercises closely for questions 9-10. I thought this page was extremely useful in explaining the different sizes and impacts of the meteors. One suggestion that I have for this page is to include what meteors are typically composed of based on density and volume. There was a problem in the exercises of this, but I figure this would be general knowledge of astronomy students in this course.

The Spherical Cow Issues page does not include enough knowledge for this lab to be its own page, in my opinion. I think this page could be added to the Definition of Scale Height background page in a few extra sentences. I like the cow included cow and the joke about it at the end, though.

2. **Simulators**

Three simulators are included in this lab. These are the Atmospheric Elevation Simulator, the Atmospheric Contents Simulator, and the Meteor Impacts Simulator. The Atmospheric Elevation Simulator correlates to questions three and 5a. in the exercises. This simulator is useful is showing the relationship between density and pressure at different elevations above sea level. I appreciated the ease of this. It was straight-forward. One area of improvement for this simulator could be to include a higher range of Scale Heights above sea level. If it included a higher range of values, this could help in other questions of the lab, as well.

Next, the Atmospheric Contents Simulator was used in exercise questions 4, 6, 7, and 8. This was my favorite simulator that was in this lab. It was useful and well-organized. I could easily see how the mass, radius, temperature, and contents of each atmosphere affected scale height. To me, this was the focus of most of the lab, so I do not have any suggestions for improving this simulator.

The last simulator is the Meteor Impacts Simulator, following exercise problems 9-10. Overall, this simulator was impactful. It easily allows the user to see the impacts of meteors of different masses, radii, and densities on different planets. This makes it simple to evaluate the contents of various planets' atmospheres, as well. The ratio feature is a little confusing, so one suggestion I would make is to determine what masses are being compared. This could be included in the background page for meteor impacts. I also liked that you could see the column of air's mass through which the meteor would be passing. The z=H measurement included on the simulator was unnecessary, in my opinion. I do not think this added much to the simulator. Overall, this simulator complements the background page and exercises well.

3. Exercises

Overall, the exercises were useful applications to the background pages and simulators. A few of them were difficult for me to understand, but this may have been different if I had a more substantial background in the subject. Providing specific formulas for exercises 1-8 would have been beneficial, in my opinion. In these first exercises, I think numbers 1 and 4 were good because of their tables. The tables in these show how different scale heights are compared, which I believe is what the lab is about.

The exercises for the Atmospheric Simulations and the Meteoroid Impact Simulations did not relate to each other very well because they are two different concepts. I think if this lab were broken into two different labs, this would be beneficial. One lab could focus on meteor impacts while the other one focuses on scale height in different atmospheres. The exercises could be broken apart into these two sections, as well.

Review on How to Increase Conceptual Learning and Decrease Calculations

One idea that I had to increase conceptual learning, as mentioned earlier, is to include the formulas needed for each problem. This would eliminate the time spent searching for the formulas and trying to apply them accurately. With this, I like the break-down of the equations presented in the Definition of Scale Height background page. This gives students an understanding of why each of the formulas is used in the way that it is; however, it is still difficult to pinpoint the method needed for each exercise in the Atmospheric Simulators.

The next idea I have to decrease calculations is to have them already presented on the simulator. Then, the goal would be to evaluate the differences of either different atmospheres (Atmospheric Contents) or different scale heights on Earth (Atmospheric Elevations). To do this, the students could determine why the atmospheres have different scale heights instead of evaluating the scale heights themselves. I think changing a few of the more challenging problems to be like this would significantly decrease the calculations. Many students dread doing calculations, so this would make it easier for them to understand, as well.

In the Meteor Impacts Exercises, I think the calculations were less complicated because they could be plugged into the simulator easily and seen from there. I do not feel the number of calculations on these exercises needs to be decreased.

Incorporation of Pluto's Atmosphere into the Lab

A few places in the lab come to mind that Pluto's atmosphere could be added easily. The first and best place for this is in the Atmospheric Contents Simulator. Pluto could be added alongside Mercury, Venus, etc. in this simulator. Then, students would compare these atmospheres to gain knowledge about Pluto's differences in pressure and density. This could make the lab flow better with questions regarding how Pluto relates to the terrestrial planets.

The next place Pluto's atmosphere could be incorporated is in the Meteor Impacts portion of the lab. Pluto's atmosphere seems to be heavily impacted by meteors and debris because it is only about 1/6 the size of the Earth. So, meteors are more likely to break into the atmosphere of Pluto. In comparison to if Pluto was added to the Atmospheric Contents Simulator, Pluto could be evaluated by being compared to the terrestrial planets and their impacts by meteors. Each of these incorporations of Pluto would also increase the conceptual understanding of the lab instead of adding calculations. This would be done by drawing conclusions about Pluto and the other terrestrial planets and bodies together.

$H = 1/e(P_0)$ etc.
$2H = 1/e^2(P_0)$

Student Guide – Scale Height – "something fades away w increasing distance" @ $q = 1/e$

Background Information

$z = \mu$

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	$P = P_0 e^{-2}$	.135
z=2.5 H	$\rho = \rho_0 e^{-\frac{2.5}{H}}$	.082
z=1.698	$P = P_0 e^{-1.698}$	0.183
z=6.00 H	$P = P_0 e^{-6}$	.00248
z=6.40	$P = P_0 e^{-6.40}$	0.00166

$.183 = \frac{1}{e^{z}}$
$\frac{1}{.183} = e^{z}$

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.

K = constant
T = temp
N = mass
m_H = mass of H atom
g = gravity

units: K = J/K T = K μ = (mass)
m_H = Kg g = m/s^2 J = $m^2/s^2 \cdot$ Kg

So, H units $= \frac{J}{Kg \; m/s^2} = \frac{J}{Kg \; m/s^2} = \frac{m^2/s^2 \cdot Kg}{Kg \; m/s^2} = \frac{m^2}{m} = H$

Scale height's units are m. H = m

Atmospheric Simulators

3. The height h½ is defined as the altitude where the density (or pressure) is half its value at the surface. Solve algebraically for the value of h½ (and then check your value in the simulator).

Density @ sea level h: $P_0 = 1 = 1.27$ Kg/m³

So, @ h½, $P_0 = .5 = .635$ Kg/m³

scale height - falls off by 1/e
most apropriate

*use venus

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	$93\rho_0$	11	$\mu = 43.44$ $D = D_0 e^{-h/H}$ $93 \cdot e^{-11/15.82} \approx$ 46.399 scale height 15.82
Earth	ρ_0	8.9	$D = D_0 e^{-h/H}$ $1 \cdot e^{-8.9/8.38} \approx$ .3461
Mars	$0.0064\rho_0$	22	$D = .0064\, e^{-22/10.67}$ $\approx$ .0000141

how tall is the atmosphere @ one scale height

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?

Density at sea level: 1.27 Kg/m³

$\frac{1}{10} \cdot 1.27 = .127$ Kg/m³, when Scale H = 2.3 H (in m)

In Km = .0023 Km

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

$P = P_0 e^{-z/H}$ $101000 e^{-1.19} = 30{,}700$ Pa

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?

$35.6 = 101 e^{-a}$ 35.6 kPa = 101 kPa $e^{\frac{z}{8.4\,km}}$

$.3525 = e^{z/8.4}$

z = 8.76 Km

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.

H

$M = Vol \cdot \delta$

$4\pi r^2 H \delta$

$4\pi \cdot (6.371 \times 10^6)(8.4 \times 10^3)(1.29 \frac{kg}{m^3}) = 9.5 \times 10^{19} kg$

7. a) Find the scale height for the planet Venus if its atmosphere was 100% H_2.

= 343.69 km

b) Find the scale height for the planet Venus if its atmosphere was 100% CH_4.

= 42.96 km

c) Find the scale height for the planet Venus if its atmosphere was 50% H_2 and 50% CH_4.

= 76.38 km

d) How accurate do you believe your answer to part c) to be? Explain. (Hint: You might find some help on the spherical cow page.) I think it is accurate to an extent. It is less than 7a) and more than 7b), which makes sense because of the weight of the gases.

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?

.2% H_2
98.4% N_2
1.4% CH_4

8.13 km was the scale height of Earth's early atmosphere. Titan is much smaller than Earth, so the scale height is larger.

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 10^7 kg and 20 meters, respectively.

a) Using these values, calculate the density of the Chelyabinsk meteor. Assume a spherical shape.

$\approx$ 2388 Kg/m^3

b) What does this value tell us about the meteor's composition—was it likely to be metallic, rocky, or icy?

It was likely rocky

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? This meteor is medium so we would have probably predicted it to do damage on Earth. However this did not happen.

d) Suppose a new meteor had the same mass as the Chelyabinsk meteor (10^7 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? The new radius would be about 7.45 m. I think the new meteor would be more likely to survive due to the amount of material it has.

10. a) A spherical stone (ρ_M=3 g/cm^3) meteorite of radius R_M = 0.5 m heads toward Earth at high velocity. What do you think is the likely outcome? Explain why?

I think the meteorite will dissolve in Earth's atmosphere because it is less dense than the atmosphere.

b)) An identical stone (with the same kinematics) heads toward Mars. What do you think is the likely outcome? Explain why?

The stone will make it farther into Mars's atmosphere. Whether it will make it ~~to~~ the surface, I'm not sure. Mars's atmoshere is less dense than Earth, so it would be likely to do damage.

c) An identical stone (with the same kinematics) heads toward Venus. What do you think is the likely outcome? Explain why?

The stone will not make it as far as Earth's + Mars's atmospheres because Venus's atmosphere is more dense + will cause it to disinigrate.

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?

$H \approx 5.29$ km

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?

The planet would not be safe due to the low surface density. The debris would hit the planet due to its relatively large size and density.

$\rho_0 H$ = density of a slab