PHYSICS 3300 Case Study - Falling through Jupiter

1 Overview

The atmosphere of Jupiter is a complex and dynamic place. The primary component is molecular hydrogen with fractional concentrations of helium and other gases in the same relative amounts as found in the sun. During a descent from the upper levels of Jupiter's atmosphere, you would fall through the exosphere, the thermosphere, stratosphere, and the lowest layer, the troposphere. Below the troposphere, atmospheric pressure makes gaseous compounds all but impossible and the gas phase atmosphere transitions to a liquid interior.

In the absence of an actual solid surface, it is traditional to define the "surface" of a gas giant as the depth at which the atmospheric pressure reaches 1 bar (pressure at the surface of the earth): $P(z = 0) = 1$ bar. The Jovian troposphere extends from a pressure of around 0.1 bar past the surface and deep into the Jovian atmosphere to at least 22 bar. All of the visible features we see - ammonia and hydrogen sulfide clouds, storms - all exist in the troposphere, which is the subject of this Case Study.

In this exercise, you will compute the dry adiabatic lapse rate (DALR) within the Jovian troposphere. You will use data from the Galileo probe, which descended through the Jovian atmosphere, radioing its data back to the Galileo spacecraft and then to earth, to estimate the environmental lapse rate (ELR) near the probe as it fell through Jupiter.

Read the two assigned papers on the structure of the Jovian atmosphere. Note any data that will help you establish the DALR within the Jovian troposphere.

2 Technical Data

The Galileo spacecraft was launched in 1989 to study the Jovian system, including Jupiter's atmosphere. The 339-kg Galileo probe was an atmospheric-entry vehicle that was released from the main spacecraft in July of 1995 and entered Jupiter's atmosphere five months later. An incredible ride: within two minutes of entering Jupiter's upper atmosphere, the probe was slowed from it's arrival speed of 47 km/sec to subsonic speeds, heating it's heat shield to 28,000 °F, and decelerating at the rate of 230g. The probe then dropped its heat shield and deployed an 8-foot parachute. It collected state data (temperature, pressure) for the next hour as it fell through the atmosphere. It stopped transmitting at an ambient pressure of 23 bars and a temperature of 307 °F.

The Jovian atmosphere consists primarily of molecular hydrogen and helium. The number ratio of the primary constituents is $He/H_2 = 0.157$.

3 Analysis

1. In your discussion groups, define the following terms and concepts with appropriate mathematical expressions involving measurable or known quantities: (1) Dry Adiabatic Lapse Rate; (2) Environmental Lapse Rate; (3) Atmospheric Scale Height; (4) Isothermal Atmosphere Model.

2. What are the concentration fractions of H_2 and He in the Jovian atmosphere? Note that the fractions must sum to one under the assumption that other gases are in low enough concentrations that we can safely ignore them.

3. Use the answer to the previous question to estimate the molar mass of an average atmospheric molecule in Jupiter's troposphere.

4. What other estimations are necessary to establish the DALR for the troposphere? Make those estimations here with well-documented reasoning.

5. Calculate the Scale Height for the Jovian troposphere and comment on its physical interpretation.

6. Calculate the DALR for the Jovian troposphere.

7. Download the temperature and pressure probe data from the link on the course website. The file should be called "ptz.tab." The file should have five columns of data. These are calibrated data files from the Galileo probe during its descent through the Jovian troposphere. A description of the column data fields is provided in the file "ptz.lbl." You will be concerned with the last three columns, which are atmospheric pressure (bars), temperature (°C), and altitude (km). Save this file as a CSV file. Use the data to create an Excel model of the Jovian troposphere by plotting Temperature vs. altitude and running a linear fit to the data to estimate the environmental lapse rate (ELR) for the troposphere. Include a plot of this data in your submission with appropriate axis labels and units.

8. Using the results of the previous analysis, determine the stability of the Jovian atmosphere and comment on the meaning of the result.

9. By performing the appropriate analysis of the pressure-altitude data in the ptz.tab file determine whether the analysis of HW problem 1.16 makes accurate predictions for the pressure variation

10. Plot the pressure vs. altitude data from the Galileo probe. Include a plot of this data in your submission with appropriate axis labels and units.

11. Recall the results of Problem 1.16 in which we assumed the temperature profile of the atmosphere was constant with altitude and derived the pressure function $P(z)$. Does your data support this model for Jupiter's troposphere? Comment on why the model works or does not work in accurately describing the pressure data recorded by the Galileo probe.

12. Under the assumption of adiabatic expansion, the pressure and temperature are related by $\frac{dT}{dP} = \frac{2}{f+2}\frac{T}{P}$. We also know that the temperature obeys $T(z) = T_0 + \Gamma_d z$ where T_0 is the temperature of the atmosphere at $z = z_0$ and Γ_d is the DALR. Derive an equation for the variation of pressure with altitude $P(z)$ incorporating the linear temperature model $T(z)$ above. Your equation should express the pressure in terms of z (altitude above some reference height z_0), the temperature $T_0 \equiv T(z_0)$ and other physical and atmospheric constants.

13. Solve the equation above for the pressure $P(z)$. In finding the solution for $P(z)$ you will introduce a new integration constant $P_0 \equiv P(z_0)$. Using the values for P_0 and T_0 obtained from the last entries in the Galileo probe data, plot your expression for $P(z)$ across the entire range of probe altitudes from z_0 to z_f where z_0 is the lowest value for the probe altitude (last entry in the data file) and z_f is the highest altitude (first entry). Note that you will need to convert your data from Pascals and meters to bars and kilometers to make a comparison with the Galileo probe data. Finally, include both calculated and probe data for $P(z)$ on your graph and comment as to the accuracy of the calculations. Can you identify additional improvements we could make to the model to more accurately predict/reproduce the experimental data?

4 Submission

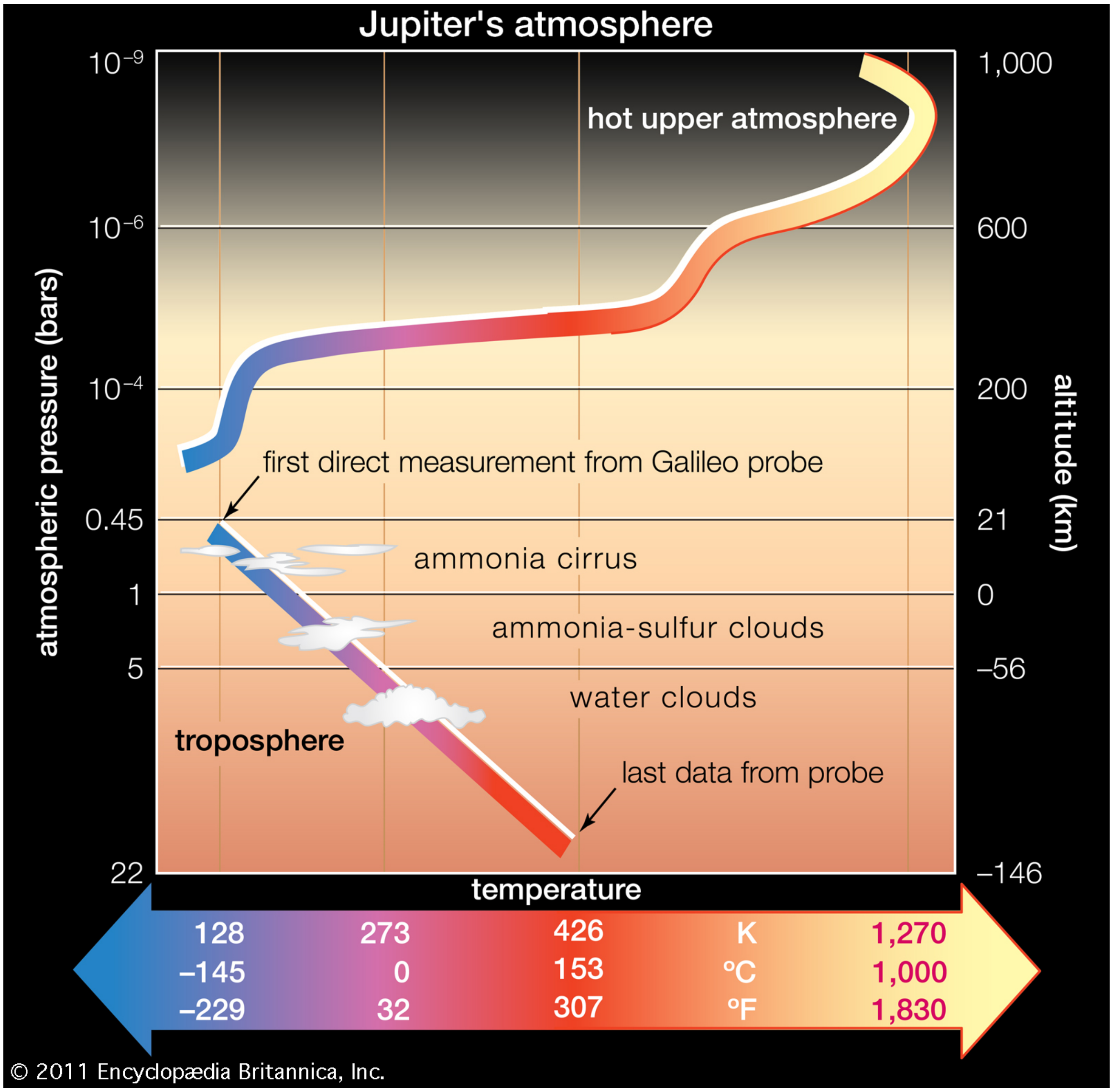

Figure 1: Structure of Jupiter's Atmosphere.

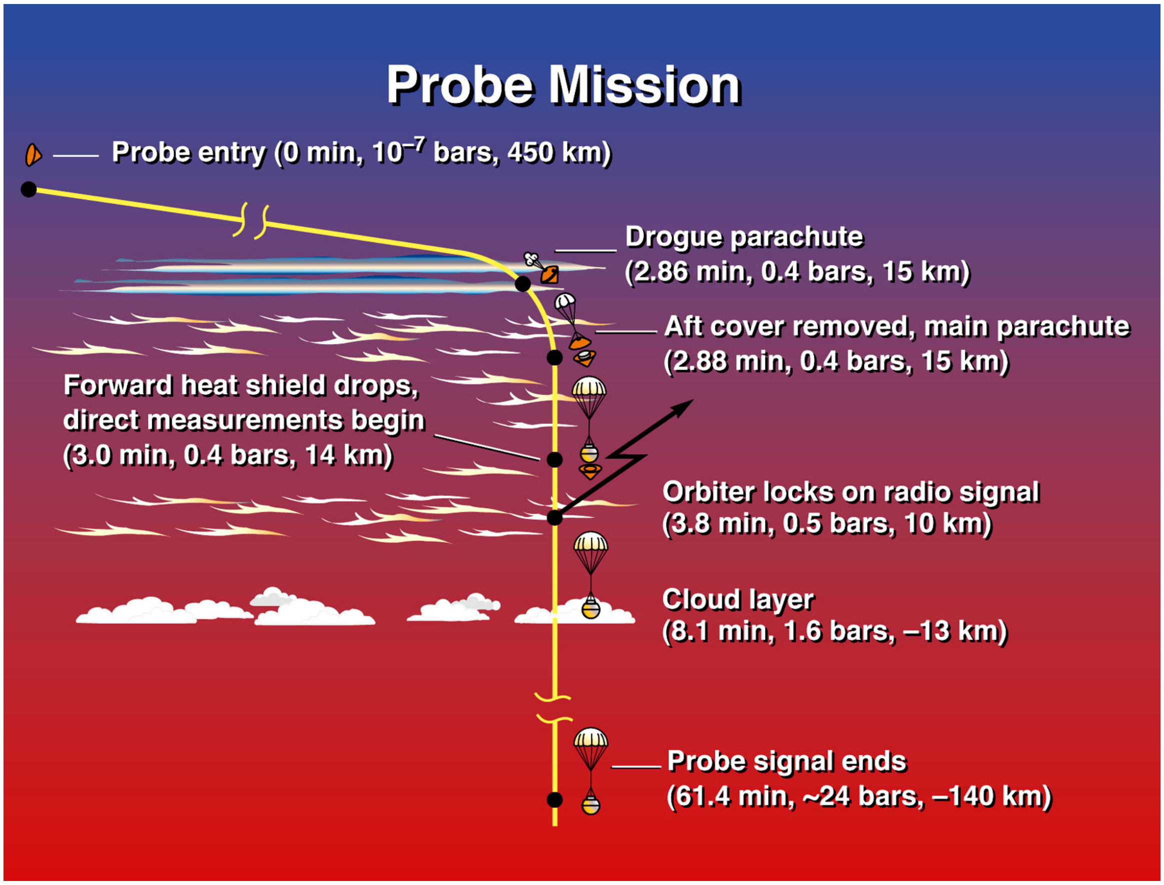

Figure 2: Galileo Probe Mission Phases.