ASTR 120 Problem Set 8: Due Tuesday, October 31, 2017

General reminders: You must show all your work to get full credit. Also, if any website was useful, you need to give the URL in your answer. Note that any website is fair game; you just have to cite it. If any book including our textbook was useful, you need to indicate where in the textbook you used a particular fact. This will be true in all homeworks.

1. [10 points] In the slides, we say that the equilibrium temperature $T_{\rm eq}$ of a planet is

$$T_{\rm eq} = \left[\frac{L(1-\alpha)}{16\pi\sigma d^2}\right]^{1/4} , \tag{1}$$

where L is the luminosity of the star, d is the distance of the planet from the star, α is the fraction of the star's light that is reflected by the atmosphere (and thus $(1-\alpha)$ is the fraction that is absorbed by the planet), and σ is the Stefan-Boltzmann constant.

a. Derive this formula. **Hint:** assume that the planet radiates like a blackbody, at a single temperature $T_{\rm eq}$ over its entire surface. Also note that although the surface area of the planet is $4\pi R^2$, where R is the radius of the planet, the planet's effective area when absorbing the star's radiation is πR^2 because from the perspective of the star the planet looks like a circle of radius R.

b. Calculate $T_{\rm eq}$ for Venus, Earth, and Mars, and compare your values with the actual average surface temperatures of each of those planets. What is the reason for the differences?

2. [10 points]

a. Using the derivation and formulae in the "exponential.pdf" file in Files→derivations→exponential, derive the scale height of Venus' atmosphere, and compare your answer with the scale height that you find on the Web. **Note:** here the point is to specify, with citations, all of the values that go into the formula. For Venus' atmosphere, explain why you do or do not expect the temperature at a given altitude to be nearly constant everywhere on the planet.

b. Assuming that there is a single scale height and a single temperature that characterizes Venus' atmosphere, derive the total mass of Venus' atmosphere by integrating the density as a function of height. Specifically, the mass should be approximately $M = 4\pi R^2 \int_0^\infty \rho(r)dr$, where $\rho(r)$ is the density a vertical height r above the surface and R is the radius of the planet. **Note:** we are assuming that the atmosphere is an ideal gas. **Note 2:** if you do not remember how to integrate an exponential, there are many references on the Web. **Note 3:** there are several numbers you will have to look up, and one of the points of this problem is that you should determine which numbers those are!

3. [5 points] The thermosphere of the Earth can reach a temperature of $\sim 2,000$ K. At this temperature, calculate the average thermal speed $v_{\rm th} = \sqrt{2kT/m}$ for a hydrogen molecule H_2,

a helium atom He, and a nitrogen molecule N_2. Compare each of those speeds with the escape speed from Earth. and use that comparison plus the escape criterion given in the lecture slides to determine which, if any, of those gases should be able to escape from the Earth's atmosphere into space.

Bonus Question [2 points]

Find an argument on the Web that global warming is a hoax, and debunk it convincingly.