

Earth 351 - Forming a Habitable Planet
 Problem Set #6 - Planetary Temperature

Name _____
 Due: Mon., May 8, 2017

1. What planetary minimum and maximum surface temperatures to be in the habitable zone?
2. One way to compare planets is via their *blackbody or effective temperatures*. To calculate this, we assume that the solar radiation per unit area at a distance D from a star with luminosity L is $L/4\pi D^2$. Thus a planet of radius r absorbs solar power at a rate proportional to the ratio of its cross sectional area πr^2 times a term $(1-A)$ where A is the *albedo*, or fraction of solar radiation reflected by the atmosphere. Thus the power absorbed is

$$P_{\text{abs}} = \pi r^2 (1-A) L / 4\pi D^2$$

If the planet radiates this power as an ideal black body, then

$$P_{\text{rad}} = 4\pi r^2 \sigma T_{\text{bb}}^4$$

where σ is the Stefan-Boltzmann constant ($5.7 \times 10^{-8} \text{ J s}^{-1} \text{ m}^{-2} \text{ K}^{-4}$) and T_{bb} is the blackbody temperature ***in degrees Kelvin***.

- a. Assuming a planet radiates all the solar power it absorbs, derive an expression for its blackbody temperature. How does this depend on the planet's radius?
- b. Compute blackbody temperatures for the four terrestrial planets, assuming they have no atmosphere ($A=0$), and $L=3.9 \times 10^{26} \text{ W}$. The planets' distances from the sun are given in the table in Astronomical Units (1 AU = $1.5 \times 10^8 \text{ km}$). Do everything in SI units and convert the final result to degrees C. This is easiest with a spreadsheet or program.
- c. The table also gives actual blackbody temperatures (i.e. including the albedo) and surface temperatures.

	D (AU)	black body T deg C	surface T deg C
mercury	0.39	169	167
venus	0.72	-42	464
earth	1	-19	15
mars	1.52	-63	-65

On one plot, plot these two temperatures and that from part 2b. for each planet as a function of their distance from the sun. The plot should have three temperatures for each planet.

2d. Compare the blackbody temperatures for A=0 with the actual ones. What is the difference and why does it arise?

e. Consider the trend of blackbody temperatures. Which planet is anomalous and why? Which planets have similar blackbody and surface temperatures? Which differ? Explain why these similarities and differences arise.

3. Earth's average albedo is 0.3, whereas Antarctica's albedo measures 0.8. If Earth were ice covered, calculate the resulting blackbody and surface temperatures in degrees K, then convert to Celsius. What would be the consequences for habitability?

4. How and when did Earth become covered by ice, a 'Snowball'? What were the consequences for life? How did the Earth get out of this frozen state? (Ward and Brownlee, Chapter 6).

5. Solar luminosity. Early in Earth's history, c. 2.8 B.Y. ago, the sun's luminosity was estimated as 20% lower than the current level. Why? To explore the possible effect repeat the calculations in problem 2 for this lower value. What might the results imply?

6. Early Earth. In “Initiation of clement surface conditions on earliest Earth”, Sleep et al., PNAS, 2001 (under 'Early Earth' on class website) present a model for Earth's surface temperature after the catastrophic collision that formed the moon. Why the special concern for 100 deg. C? What does the model suggest about the time this temperature was reached? What geological evidence provides an independent record of temperature?

7. From reading "Why did the United States retreat from the moon?" what do you think are three key points relevant to the issue of whether the US should start a program for human exploration of Mars? Also, on classwebsite, References, under “Space Policy, Mars Exploration”.

<http://www.sciencedirect.com/science/article/pii/S0265964614001209>