What Should the Temperatures of the Terrestrial Planets Be? **Due: Oct. 13, 2017**

Name:______________________________________

The temperatures of planets can be estimated using the absorption and radiation of energy. The amount of energy that a planet *absorbs* from Sun is given by:

$$\text{Energy absorbed} = \frac{S}{4}(1-A) \qquad (1)$$

where S (the apparent brightness) is the amount of energy received from the Sun, and A is "albedo" – the amount of energy that is *reflected* back into space. This is the amount of energy received for every square meter of the Earth, on average, over time. Some places, like near the poles, receive less energy than this overall average, and some places (near the equator) receive more energy on average. At any given location, much sunlight is received during the day, but none at night.

I. Apparent Brightness (S)

S is the apparent brightness in Watts per square meter. For Earth, S is about 1,367 Watts per square meter.

$S = \dfrac{L}{4\pi d^2}$ where L is the luminosity of the Sun, 3.9×10^{26} Watts, d = distance

What is the apparent brightness of the Sun for each of the terrestrial planets? We calculate this because it determines how much energy each planet can receive from the Sun.

II: Example - Mercury:

Mercury is 58,000,000 km from the Sun. How many meters is this? It's (5.8×10^7 km)(10^3 m/km) = 5.8×10^{10} meters. 4π is equal to 12.566, so

$$S_{Mercury} = \frac{(3.9x10^{26} Watts)}{(12.566)(5.8x10^{10} meters)^2} = \underline{\hspace{6cm}} \frac{Watts}{m^2}$$

III: Repeat this calculation, using information for each planet (That is, fill in column 3 and column 4 – we'll get to the last column on the next page):

Planet:	Distance to Sun (km)	Distance from Sun (m)	S_{planet} (Watts/m^2)	Albedo	Radiating Temp. (K)	Radiating Temp. (ºC)	Actual Temp.
Mercury	5.8×10^7			0.06			170°C
Venus	1.09×10^8			0.65			460°C
Earth	1.50×10^8			0.3			15°C
Mars	2.28×10^8			0.15			-55°C

IV. Getting the radiating temperature: If the temperature of the planet is constant on average, then another simple law of physics is that the amount of energy that a planet gets from the Sun must be exactly balanced by how much energy it gives off again. If a planet is "keeping" more energy from the sun than it radiates to space again, its total energy content must rise (which is the same thing as saying that the temperature will rise). If a planet loses more energy than it gains, its temperature decreases. Only when input and output of energy are equal does the temperature remain constant.

The amount of energy, in Watts per square meter, is given by the Stefan-Boltzmann law:

Watts per square meter radiate due to temperature: σT^4

SO – to calculate the radiating temperature of each planet – **the temperature of the surface assuming there is no atmosphere** – all we have to do is make expression 1 equal to expression 2:

$$\sigma T^4 = \frac{S}{4}(1 - A)$$

This is the mathematical way of making the energy output equal to the energy input. All we have to do now is solve for T, which is just a bit of algebra:

$$T = \sqrt[4]{\frac{S}{4\sigma}(1 - A)}$$

where **σ** is a number – a constant – equal to 5.67×10^{-8} W/m^2/K^4, otherwise known as the **Stefan-Boltzmann constant**. **Use this expression to fill in the last column of the table above!!!** This equation gives the temperature in Kelvin (K). Convert to Celsius (^{o}C) to complete the final column (subtract 273 from the temperature in Kelvin). NOTE… these are not the true temperatures. Let's compare them to the true (measured) average surface temperatures of the planets and think about why they are different.

V: How well do the calculations you did and the measured temperatures you plotted above compare? Please answer the following:

1. Which planets have the biggest difference between the calculated temperature and the measured temperature?

Let's consider the atmospheres of the planets. They are very different.

Compare to atmospheric compositions:

Mercury:	No atmosphere – no CO_2
Venus:	Atmosphere 90 times thicker than Earth, 95% CO_2. This means that the pressure of CO_2 is 90x(0.95) = 85.5 Earth atmospheres of CO_2.
Earth:	Atmosphere is currently about 0.00039 of an atmosphere of CO_2
Mars:	Atmosphere is 95% CO_2, but 150 times thinner than Earths, which leaves 0.000063 of an Earth atmosphere of CO_2 (so, less than Earth).

2. Which planets have the most CO_2 in their atmospheres?

D. Is it true that the planets with the most CO_2 in their atmospheres also have temperatures much higher than the calculated temperatures (which assume no atmosphere)?

E. What is the effect of the CO_2, given our calculations and observations above?

F. What would the Earth's temperature be without its atmosphere?

G. The Earth's average temperature – averaged over all places and times – is about 15°C (or about 273 + 15 or 288K). How much warmer is Earth's surface because of the atmospheric greenhouse effect?