

1. Using the radii of Earth and Sun, calculate the ratio of Sun's volume to Earth's volume.
2. The Earth-Sun distance varies from its mean by $\pm 1.75\%$ over the course of a year (closest 4 January, farthest 5 July). How much does this affect the flux of solar radiation (W m^{-2}) incident on the planet?
3. Assume that the Sun starts initially as pure hydrogen with a mass of 2×10^{30} kg, and maintains luminosity at its present value of 3.85×10^{26} Watts, constant over its entire lifetime. How long would it take to convert all the H to He, assuming that 0.7% of the mass of a He atom is converted to energy for each He atom produced? [The actual lifetime is less than this because the Sun becomes unstable long before all the H is burned, and becomes a red giant.]
4. What fraction of the Sun's luminosity is intercepted by the Earth?

1. The solar constant at Earth's orbit is 1370 W m^{-2} , and the distance from Jupiter to the Sun is 5.2 times the Earth-Sun distance. Knowing only these two facts, calculate the solar constant at Jupiter's orbit.
2. The orbit of Mars has eccentricity $e = 0.093$. On a surface perpendicular to the solar beam at the top of the Martian atmosphere, what is the ratio of solar flux at perihelion to that at aphelion?
3. Compute the solar zenith angle at 9 am (local sun time) at Seattle at summer solstice, equinox, and winter solstice.
4. Compute times (and hour-angle) of sunrise and sunset in local-sun-time, for Seattle at summer solstice, equinox, and winter solstice. What is the length of day in hours (sunrise to sunset)? [Assume the Sun sets at zenith angle 90° ; do not take into account refraction or the finite width of the Sun.]
5. On the December solstice, what is the flux of solar radiation (W m^{-2}) at the top of the atmosphere for Seattle (47.5°N) at noon? What is it for San Diego (32.8°N) and Anchorage, Alaska (61°N)? Note how different these values are. Compute the ratios Anchorage:Seattle:San Diego. Then compare the same three cities for noon on the June solstice. How does this result relate to the patterns you see on page 16 of the handout (or Figure 1.6 of Hartmann)?
6. Compute the average solar flux over the course of a day, $\bar{F}$, at Seattle for summer solstice, equinox, and winter solstice. [You can check your answer by looking at Figure 2.6 of Hartmann.] You may make the approximation that the earth-sun distance doesn't change much in the two weeks between solstice and perihelion (or aphelion).

1. (3 points). Calculate the effective temperature T_e of the earth for various values of planetary albedo α_p :
 - (a) The present earth ($\alpha_p = 0.3$)
 - (b) A cloud-free earth ($\alpha_p = 0.15$)
 - (c) A snow-covered earth with the albedo of Antarctica
(Antarctic surface albedo = 0.8; Antarctic planetary albedo = 0.7)

2. (2 points). The total atmospheric pressure at sea level is 1013.25 millibars or 101325 Pascals. Knowing the acceleration of gravity, compute the mass M of a column of atmosphere (kg m^{-2}).

3. (3 points) The CO_2 content of the atmosphere is increasing by 1.8 ppmv (or 2.8 ppmm) per year, where ppmv means parts-per-million by volume and ppmm means parts-per-million by mass. If this increase is all due to coal burning, and there are no other sources or sinks of CO_2 , how many kilograms of coal are burned per person per day, on average, to cause the observed increase of CO_2 ? [Assume coal is pure carbon, and assume the human population is 7 billion.]

4. (3 points) (Hartmann problem 2-1) Use the data in Table 2.3 to calculate the effective temperatures for all the planets. The actual emission temperature of Jupiter is about 124 K. How can you explain the difference between the number you obtain for Jupiter and 124 K?

5. (3 points) Estimate the effective emission temperatures of the planets, as indicated by their wavelengths of maximum emission:

<i>Planet</i>	<i>wavelength (μm)</i>
Mercury	6.6
Venus	12.8
Earth	11.4
Mars	13.4
Jupiter	23.4

1. (4 points) Define F_B as the total radiation flux emitted by a blackbody (W m^{-2}).
 - (a) From the Stefan-Boltzmann law, obtain an expression for dF_B/dT .
 - (b) For a temperature increase of 1 K, what will be the increase of emitted radiation? Do this for the earth's average surface temperature ($+15^\circ\text{C}$), and for the temperature at the 6-km level in the atmosphere (-18°C).
 - (c) When measurements of infrared flux at the top of the atmosphere ("outgoing longwave radiation", OLR) are correlated with surface temperature, the slope is $dF/dT_s \approx 1.83 \text{ W m}^{-2}\text{K}^{-1}$. Compare this to your result and speculate on the reason for the difference.

2. (5 points). A one-layer atmosphere with longwave emissivity ϵ , zero longwave reflectivity, and zero shortwave absorptance is located over a black ground surface. Given solar constant $S_0=1370 \text{ W m}^{-2}$ and planetary albedo $\alpha_p=0.3$, and assuming radiative equilibrium, plot the global average ground temperature T_g and atmospheric temperature T_a , both versus ϵ for values of ϵ between 0 and 1.

3. (3 points). Kirchhoff's law.

At night on a flat desert surface, the ground temperature is $T_g = 250 \text{ K}$ and ground emissivity is $\epsilon_g = 0.9$, independent of wavelength in the infrared. A thick stratus cloud moves in to cover the region. The cloud has infrared emissivity $\epsilon_c = 1.0$; the atmosphere between the cloud and the ground is transparent to infrared radiation. The upward radiation flux measured with a pyrgeometer at 2 meters above the surface is $1.05 \sigma T_g^4$, where σ is the Stefan-Boltzmann constant. Find the temperature T_c of the cloud base. [Hint: Do not assume radiative equilibrium.]

(a) Assume the heat capacity of the atmosphere is $1004 \text{ J kg}^{-1}\text{K}^{-1}$, and that the mass of the atmosphere per unit area, M , is given by $Mg = p_o$, where p_o = sea-level pressure = 101325 N m^{-2} and g = acceleration of gravity = 9.8 m sec^{-2} . Show that the thermal inertia of the atmosphere (the amount of heat required to raise the temperature by 1 K) is $10^7 \text{ J m}^{-2}\text{K}^{-1}$.

(b) In Latitude Zone X, an average of 10 cm (liquid equivalent) of precipitation is measured at the surface during the month of April. Compute the rate of energy released (W m^{-2}) in the atmosphere by condensation of water vapor in April. Also compute the heating rate of the atmosphere in April due to latent heat release, in degrees per day, in this latitude zone.

(1) Hartmann page 114, Exercise 1.

(2) Hartmann page 114, Exercise 3. [The drag coefficient is unitless, $C_D=2\times 10^{-3}$. The first edition of the textbook erroneously specified units s^{-1} .]

(3) Hartmann page 114, Exercise 4. "In equilibrium" means $G=0$, so $R_s=LE+SH$, where SH is given by Eq. 4.26.

(4) How many one-megaton bombs would it take to melt the entire Antarctic ice sheet?

Useful information:

The ocean covers 70% of the Earth's surface.

The Antarctic ice sheet mass is 60 meters of "sea-level equivalent".

Assume the ice has an average temperature of -20°C .

Heat capacities and latent heats are given on page 374 of Hartmann's textbook.

1 Megaton is equivalent to 10^{15} calories or 4.186×10^{15} Joules.