

Solar radiation and Earth's temperature

Energy Systems workshop, fall week 8

15 Nov. 2004 (EJZ)

We would like to understand why the Earth has the temperature it does, and what it depends on. In the process, we will develop a deeper understanding about the physics of radiation, and apply some concepts you have learned to an important problem.

Q1: What is radiation, in terms of heat transfer? Can it travel through space? If so, how?

A. Radiation basics: Earlier this quarter we learned that $\text{Flux} = \text{power}/\text{area}$.

What are the units of power? _____ Units of Area? _____

What are the units of flux? _____

If we know the power radiated by an object and our distance away from it, we can find the object's flux at our location. You did this earlier for a light bulb. Q2: What is the radiant flux one meter away from a 100 W light bulb? Hint: First find the area A of the sphere into which the bulb radiates.

$A =$

Power =

Flux =

B. Radiation from the Sun: As described in Box 5-2 of Kaufmann and Freedman's *Universe*, "Tools of the Astronomer's Trade," astronomers have measured the intensity (or flux) of solar radiation above the Earth's atmosphere. This "solar constant" $I = 1370 \text{ W/m}^2$ is the intensity of radiation far from the Sun, at the distance of the Earth's orbit, $d = 1.5 \times 10^{11} \text{ m}$. What is the area of the sphere into which the Sun radiates, at this distance?

Area Earth's orbit =

Q3: Use this to **find the total power radiated by the Sun**. $\text{Power} = \text{Flux} * \text{Area} =$

You should find that total power emitted at the Sun's surface is on the order of 10^{26} W .

We call this power the Luminosity of the Sun $= L_{\odot} =$ _____

In order to **find the flux radiated by the Sun** at its surface, you need to know its size:
 $R_{\odot} = 7 \times 10^8 \text{ m}$. What is the area of the Sun's surface? $A_{\odot} =$

Q4: Use this to find the radiation flux from the Sun's surface, $F_{\odot} =$

You should find something on the order of 10^{7-8} W/m^2

C. Temperature of the Sun: Now that you know the radiation flux from the Sun, you can find its temperature, using another expression for flux that you learned earlier this quarter. The Stefan-Boltzmann law for blackbody radiators is: $\text{Flux} = F = \sigma T^4$

What must be the (SI) units of the Stefan-Boltzmann constant σ ? _____
Its value is 5.67×10^{-8} .

Blackbodies are theoretical objects which absorb and re-radiate all the energy that falls on them. Stars are approximately blackbodies. The Sun is not quite a perfect blackbody (due to surface absorption and emission lines), but it is close. We will call T_{eff} the blackbody Sun's effective temperature. Q5: Use $F_{\odot} = \sigma T_{\text{eff}}^4$ to find T_{eff}

What is this in Celsius? _____ In Fahrenheit? _____

D. Temperature of the Earth: We can also use the Stefan-Boltzmann law to approximate T_{earth} . You already know the flux of solar radiation at the Earth's location, $I =$ _____
Use $F = I = \sigma T_{\text{Earth}}^4$ to find T_{Earth}

Q6: What is this in Celsius? _____ In Fahrenheit? _____

Q7: Is this reasonable? Why or why not? What effects were ignored in our calculation? Discuss it with your team.

E. Greenhouse Effect. The attached essay by Barbara Goss Levi will lead us through a more detailed consideration of radiation received and radiated by the Earth, taking into consideration some of the effects you noted in Q7. (Halliday and Resnick, Fundamentals of Physics, 4th edition)