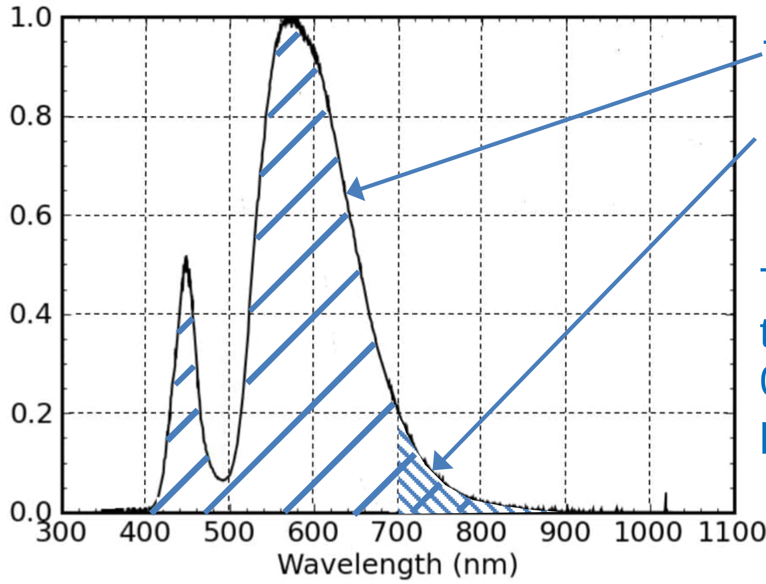
Physics 157 Tutorial 4

Name:
Student number:
Group member names:

In this tutorial, you will get some practice with problems involving radiation. Hints and useful formulae are at the back.

Question 1: The picture below shows the spectrum of an LED light emitting a total of 10 W of electromagnetic radiation. The vertical scale is in arbitrary units. You would like to know how much power the LED emits in the infrared.



Total area ~ 8 squares

Infrared part is a bit less than half a square, say 0.45

The fraction of the total area in the infrared is about 0.45 / 8 = 0.0506. The power in the IR portion of the spectrum is then: P_{IR} ~ 0.0506 x 10 W ~ 0.5 W

The point of this problem is to recognize that the graph shows how the power of the radiation is distributed between different wavelengths. The fraction of the total power radiated in a certain wavelength range is equal to the fraction of the area under the graph that lies in that range of wavelengths. For example, if we want to know the fraction of power emitted in wavelengths between 600 and 700 nanometers, we could shade in the region between the x-axis and the curve, and then estimate what fraction of this shaded area is in the vertical strip between 600 and 700 nm. The grid on the graph should be helpful in estimating the area fraction.

Using this method, estimate how much power the LED emits in the infrared. There is no universally accepted definition of the range of wavelengths considered to be in the infrared region of the spectrum. However, the most common definition is to take it to extend from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 millimeter (mm). So, in this problem, you should consider infrared radiation to be the radiation with wavelengths larger than 700 nm. There is a hint on the last page.

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Question 2: Star A has half the radius and gives off light with half the peak wavelength as compared with star B. The total power of radiation produced by star A (assuming both have emissivity e = 1) is approximately:

a) 1/16 time that of star B

b) 1/8 times that of star B

c) 1/4 time that of star B

d) 1/2 time that of star B

e) equal to that of star B

f) 2 times that of star B

g) 4 time that of star B

h) 8 times that of star B

$\lambda_A = 1/2\ \lambda_B$
So, $T_A = 2\ T_B$ by Wien's Law
$H = 4\ \pi\ R^2\ \sigma\ e\ T^4$
R is ½ for A and T is double
So, H is 4x for A

Question 3: A planet orbiting a nearby star lies at a distance D from that star. The star has radius R and the planet has radius r, emissivity e = ½, and albedo 0. If the intensity of radiation from the star at the location of the planet is I_s, the equilibrium surface temperature T of the planet (assumed to be uniform over the surface) satisfies:

a) $\pi\ r^2\ I_s = 2\ \pi\ r^2\ \sigma\ T^4$

b) $2\ \pi\ D^2\ I_s = \pi\ r^2\ \sigma\ T^4$

c) $\pi\ R^2\ I_s = 2\ \pi\ r^2\ \sigma\ T^4$

d) $2\ \pi\ R^2\ I_s = \pi\ r^2\ \sigma\ T^4$

e) $4\ \pi\ r^2\ I_s = 2\ \pi\ r^2\ \sigma\ T^4$

f) $\pi\ r^2\ I_s = \pi\ r^2\ \sigma\ T^4$

$H_{in} = H_{out}$
$\pi\ r^2\ I_s = 4\ \pi\ r^2\ \sigma\ e\ T^4$
Since e = ½, we have $\pi\ r^2\ I_s = 2\ \pi\ r^2\ \sigma\ T^4$

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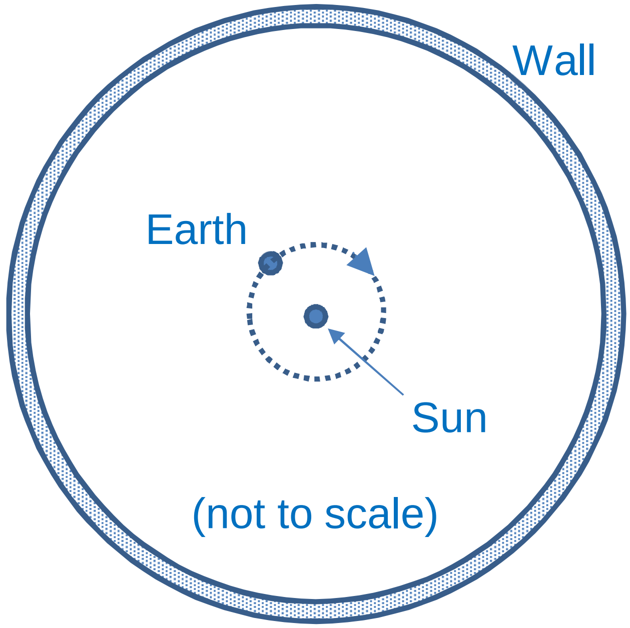
Question 4: To drum up support for his reelection campaign, Donald Trump proposes to build a spherical wall around the solar system, just outside the orbit of Neptune (sorry, Pluto), in order to keep aliens from entering the United States.



a) What would be the equilibrium temperature of this wall? There is a hint on the last page.

Useful constants:
- Distance from Sun to wall: 5 billion km
- Distance from Sun to Earth: 1.5 million km
- Intensity of sunlight at Earth: 1.4 kW/m^2
- $e_{wall} = 1$ $a_{wall} = 0$ (albedo)

For the wall, H_{in} from the absorbed sunlight equals H_{out} from the radiation in to space. If T is the equilibrium temperature of the wall, we have:

$H_{out} = A_{wall}\,\sigma\,e_{wall}\,T^4 = A_{wall}\,\sigma\,T^4$

Since the albedo is zero, the absorbed radiation from sunlight is:

$H_{in} = I_{wall}\,A_{wall}$ (which also equals $I_{earth}\,4\,\pi\,R_{s\text{-}e}^2$)

So, the equilibrium temperature is determined by

$H_{in} = H_{out}$

$I_{wall}\,A_{wall} = A_{wall}\,\sigma\,T^4$

$T = (I_{wall} / \sigma)^{1/4}$

The intensity at the wall is related to the intensity at Earth by

$I_{wall} = I_{earth} / (R_{wall} / R_{earth})^2$

So,

$T = [(I_{earth}\,R_{earth}^2)/(\sigma\,R_{wall}^2)]^{1/4} = 69\text{ K}$

b) What would the temperature of the wall be if the albedo of the wall were 0.5 instead of 0?

If the albedo were 0.5, T would still be 69 K since any light reflected from the wall would just hit the wall again until it was absorbed.

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Useful formulae:

Wien Displacement Law: $\lambda_{max} = b/T$ where $b = 2.9 \times 10^{-3}$ m·K.

Stefan-Boltzman Law for power in radiation: $H = A\, e\, \sigma\, T^4$

Stefan-Boltzman constant: $\sigma = 5.67 \times 10^{-8}$ W/(m^2·K^4)

Intensity is energy per time per area.

Intensity at distance R from a spherical source radiating power H: $I = H / (4 \pi R^2)$

This means that the ratio of the intensity I_2 at distance R_2 to the intensity I_1 at distance R_1 is: $I_2 / I_1 = (R_1 / R_2)^2$

Hint for question 1:

- You can use the squares on the graph as your basic unit of area when estimating the ratio. It can be helpful to subdivide the squares into smaller squares!

Hint for question 4:

- You do not need to consider inward radiation from the wall, since this will just be absorbed by the wall again. You can also ignore incoming radiation from outside the wall.