Physics 1010: The Physics of Everyday Life

TODAY

• Black Body Radiation, Greenhouse Effect
Admin Stuff

• Exams are at back of room, alphabetically in four piles. Please collect AFTER class
• Grades posted on website
• Average for exam was ~70%
Black Body Radiation

- All bodies radiate according to their temperature
- A “black” body is a body that absorbs all radiation incident upon it
- Total energy radiated per unit area given by Stefan-Boltzmann Law

\[ P = \sigma T^4 \]

- \( P \) = power radiated per unit area
  - = energy radiated per unit time per unit area

https://solarsystem.colorado.edu
A black body is easy to construct:
Consider a large cavity with a tiny hole drilled into it. Of all the light that goes through the hole, only an insignificantly small amount gets reflected back out. The rest is bounced around the interior of the cavity so many times, that it is finally totally absorbed. The cavity is then a "Black Body".

https://solarsystem.colorado.edu/applets/stellarOutput/physics.html

\[ P = \sigma T^4 \]
Total Solar Power Output

The radius of the sun is 696,000km. Its surface temperature is 5800K, what is the total power radiated by the sun?
The surface area of a sphere is given by $A = 4\pi R^2$
Stefan constant: $\sigma = 5.67 \times 10^{-8} \text{ J K}^{-4} \text{ m}^{-2} \text{ s}^{-1}$

A) $3.83 \times 10^{26} \text{ W}$  B) $3.83 \times 10^{30} \text{ W}$  C) $3.83 \times 10^{20} \text{ W}$  D) $3.83 \times 10^{16} \text{ W}$

The total power output of a star is call the Luminosity of the star
Total Solar Power Output

The radius of the sun is 696,000km. Its surface temperature is 5800K, what is the total power radiated by the sun?
The surface area of a sphere is given by \( A = 4\pi R^2 \)
Stefan constant: \( \sigma = 5.67 \times 10^{-8} \text{ J K}^{-4} \text{ m}^{-2} \text{ s}^{-1} \)

A) 3.83*10^{26} W  B) 3.83*10^{30} W  C) 3.83*10^{20} W  D) 3.83*10^{16} W

\[
P_T = L_S = 4\pi R^2 \sigma T^4 = 4\pi (696 \times 10^6 \text{m})^2 \times (5.67 \times 10^{-8} \text{ J/K}^4/\text{m}^2/\text{s}) \times 5800^4 \text{K}^4 = 3.90 \times 10^{26} \text{W}
\]

The total power output of a star is call the \textbf{Luminosity} of the star
Total Power Intercepted by Earth

The Earth circles the sun at 150,000,000km, and its radius is 6400km.
What fraction of the sun’s power is incident on the Earth?

A) $4.55 \times 10^{-5}$  B) $4.55 \times 10^{-10}$  C) $4.55 \times 10^{-15}$  D) $4.55 \times 10^{-20}$
Total Power Intercepted by Earth

The Earth circles the sun at 150,000,000km, and its radius is 6400km. What fraction of the sun’s power is incident on the Earth?

A) 4.55*10^{-5}  
B) 4.55*10^{-10}  
C) 4.55*10^{-15}  
D) 4.55*10^{-20}

\[ \pi R_E^2 / 4 \pi R_O^2 = \left( \frac{1}{4} \right) \left( \frac{6400 \text{ km}}{1500000000 \text{ km}} \right)^2 = 4.55 \times 10^{-10} \]

At the Earth’s distance from the sun, the total solar power is spread over the area of a sphere of radius 150,000,000km, but the Earth covers only a circle of radius 6400km out of all that area.
Total Power Radiated by Earth

The Earth absorbs 70% of the solar power incident upon its surface. What is the total power radiated by Earth?

A) $1.22 \times 10^8$ W  B) $1.22 \times 10^{11}$ W  C) $1.22 \times 10^{14}$ W  D) $1.22 \times 10^{17}$ W
Total Power Radiated by Earth

The Earth absorbs 70% of the solar power incident upon its surface. What is the total power radiated by Earth?

A) $1.22 \times 10^8$ W  B) $1.22 \times 10^{11}$ W  C) $1.22 \times 10^{14}$ W  D) $1.22 \times 10^{17}$ W

Conservation of Energy: at equilibrium, the Earth has to radiate as much power as it receives from the sun, or else it would either heat up or cool down

$$P_{\text{out}} = 0.7 \times P_{\text{in}} = 0.7 \times (4.55 \times 10^{-10}) \times (3.83 \times 10^{26} \text{ W}) = 1.22 \times 10^{17} \text{ W}$$
“Naked” Earth Temperature

What would the temperature of the Earth be if it has to radiate $1.22 \times 10^{17}$ W, and it had no greenhouse effect? $T_{\text{kelvin}} = T_{\text{celsius}} + 273$

A) -18°C  B) 0°C  C) 18°C  D) 32°C

$$P_{\text{out}} = (4\pi R_E^2) \sigma T_{Eb}^4$$
“Naked” Earth Temperature

What would the temperature of the Earth be if it has to radiate $1.22 \times 10^{17}$ W, and it had no greenhouse effect? $T_{\text{kelvin}} = T_{\text{celsius}} + 273$

A) -18°C  B) 0°C  C) 18°C  D) 32°C

$$P = 4\pi R_E^2 \sigma T^4 \implies T = \left( \frac{P}{4\pi \sigma R_E^2} \right)^{1/4} =$$

$$= \left[ \frac{1.22 \times 10^{17}}{(4\pi \times (5.67 \times 10^{-8}) \times (6,400,000)^2)} \right]^{1/4} = 254^\circ K = -19^\circ C$$
Greenhouse Effect

- Sun (5800 °K) radiates mostly at optical wavelengths
- Earth (~300 °K) radiates mostly at infrared wavelengths
- Greenhouse gases in atmosphere absorb some IR wavelengths, let others pass to space
- Greenhouse gases re-radiate absorbed energy in random direction, so half goes back to the ground.
- Overall effect:

\[ P_{\text{out}} = (4\pi R_E^2) \frac{\sigma T_{Eg}^4}{(1 + \tau)} \]

\(\tau\) is the greenhouse strength
Greenhouse Effect

• For one-layer atmosphere, the incindent power, $I_s$, is absorbed by the ground.
• The ground then radiates back $I_g$
• Some of $I_g$ gets absorbed by the atmosphere, and some is allowed to escape

• The absorbed power gets re-radiated in a random direction, so on average half goes to space and half back to the ground
• So now we have $I_s + I_a$ absorbed by ground, so the ground has to have a higher $T$. 
"Greenhouse" Earth Temperature

What would the greenhouse strength of the Earth’s atmosphere be if it has to radiate $1.22 \times 10^{17}$ W, and its Average temperature is $288 \, ^\circ$K? $T_{\text{kelvin}} = T_{\text{celsius}} + 273$

A) 0.33  B) 0.65  C) 1.35  D) 2.7

$$P_{\text{out}} = (4\pi R_E^2) \frac{\sigma T_{Eg}^4}{(1 + \tau)}$$
“Greenhouse” Earth Temperature

What would the greenhouse strength of the Earth’s atmosphere be if it has to radiate $1.22 \times 10^{17}$ W, and its average temperature is 288 °K? $T_{\text{kelvin}} = T_{\text{celsius}} + 273$

A) 0.33  B) 0.65  C) 1.35  D) 2.7

$$P_{out} = \left(4\pi R_E^2\right) \frac{\sigma T_{Eg}^4}{(1 + \tau)}$$

$$\tau = \frac{4\pi R_E^2 \sigma T_{Eg}^4}{P_{out}} - 1 = 0.65$$
“Greenhouse” Venus Temperature

- Venus has a multi-layer atmosphere
- Each layer increases $\tau$ by one
- For Venus, $\tau=121$
- The temperature of Venus is 3.3 times greater than it would be without the greenhouse effect ($732^\circ K$ instead of $220^\circ K$)