Lecture 03

Content Goals

• Temperature Scales: Absolute Temperature Scale
• Thermal Energy
• Blackbody Radiation
• Energy Flux
Temperature Scales

\[ T_F = \left( \frac{9}{5} \right) T_C + 32 \]

\[ T_C = (T_F - 32) \left( \frac{5}{9} \right) \]

\[ T_K = T_C + 273 \]
ICLICKER QUESTION

At $T = 273$ K

- a) water boils
- b) ice melts
- c) steam condenses
- d) a) and c)
- e) atoms cease motion

$T_K = T_C + 273$
Temperature and Thermal Energy

The total thermal energy is proportional to the temperature (in Kelvin)

Thermal Energy \((TE)\) is proportional to \((\text{number of molecules}) \times (\text{average molecular KE})\)

\[ TE = k \times (\text{number of molecules}) \times \text{temperature} \]

\[ TE = k n T = k_B T \]

\(T\) is temperature in Kelvin

Boltzmann's Constant

Kinetic Energy \(KE = \frac{1}{2} mv^2\)
ICLICKER QUESTION

At $T = 0$ K

a) water boils
b) ice melts
c) steam condenses
d) water freezes
e) atoms cease motion
Blackbody

• A blackbody is an object that absorbs all the radiation that is incident on it.

• The Sun is a blackbody; it absorbs any light that shines on it.
Blackbody

• If the Sun absorbs all incoming light why it does not appear black?

• A blackbody only appears black when it is at absolute zero ($T_K = 0$).

• At any non zero temperature it will emit electromagnetic radiation.
Blackbody Power Emission

The power emitted by a blackbody depends on only two things:

• the surface temperature \((T)\) of the object and
• the surface area \((A)\) of the object.

\[ P = \sigma A T^4 \]

*Stefan – Boltzmann's Constant*
Blackbody Radiation Basics

As an object gets hotter, its main color goes from red to blue.
Blackbody Radiation Basics

1. As an object gets hotter, its main color goes from red to blue.

\[ \lambda_{peak} = \frac{(2.8 \times 10^{-3} \text{ m} \cdot \text{K})}{T} \]

2. A hot object emits much more light than does a colder one

\[ I = \frac{P}{A} = \varepsilon \sigma T^4 \]

*Stefan–Boltzmann's Law*
Determine the Power Emitted by the Sun

Data:
- Radius of the sun \( R_{\text{sun}} = 7 \times 10^8 \text{m} \)
- Sun’s surface temperature \( T_{\text{sun}} = 5800 \text{K} \)
- Stefan-Boltzmann Constant \( \sigma = 5.67 \times 10^{-8} \text{W/m}^2 \cdot \text{K}^4 \)

Area of a sphere \( A_{\text{Sphere}} = 4\pi R^2 \)

Stefan-Boltzmann Law \[ I = \frac{P}{A} = \epsilon \sigma T^4 \]

\( \epsilon = 1 \) for a perfect blackbody
Determine the Power Emitted by the Sun

Stefan-Boltzmann Law

\[ \frac{P}{A} = \sigma T^4 \quad \Rightarrow \quad P = \sigma A T^4 \]

\[ P = \left( 5.67 \times \frac{10^{-8} W}{m^2 \cdot K^4} \right) \left( 4\pi [7 \times 10^8 m]^2 \right) (5.8 \times 10^3 K)^4 \]

\[ P = 3.94 \times 10^{26} W \]
Solar Energy Flux

• The power emitted by the Sun spreads out uniformly.

• The energy flux, as a function of the distance $D$ from the Sun, goes like $1/D^2$
Solar Energy Flux

• At the distance that the Earth is from the Sun (1AU) the energy flux is $1350 \text{ W/m}^2$

• Taking into account the Earth’s curvature and the fact that only ½ of the Earth faces the Sun then the average flux is less by a factor of ¼ (i.e. $337.5 \text{ W/m}^2$)

$1AU = 1.5 \times 10^{11} m$
Power Absorbed by The Earth

The Earth doesn’t absorb all of the energy incident on it:

- water, snow, clouds etc., reflect about 30% of the incident energy.

This is called the albedo.
Power Absorbed by The Earth

Considering the albedo the solar power absorbed by the earth is: \(236 \ W/m^2\) \((2.4 \times 10^2 \ W/m^2)\)

Does the Earth just keep absorbing solar power getting hotter and hotter?
ICLICKER QUESTION

If you double the absolute temperature, the total radiation

\[ P = \sigma A T^4 \]

a) Increases by a factor of 4
b) Decreases by a factor of 1/4
c) Decreases by a factor 1/16
d) Increases by a factor 16
e) None of the above
In Class Activity

• Stefan – Boltzmann Law: \( I = \sigma T^4 \)

• Intensity = \( \frac{\text{Power}}{\text{Area}} \) \( I = \frac{P}{A} \)

• Area of a sphere: \( A_{\text{Sphere}} = 4\pi R^2 \)

• Radius of the sun \( R_{\text{Sun}} = 7 \times 10^8 \) m

• Sun's surface temperature \( T_{\text{Sun}} = 5.8 \times 10^3 \) K

• Stefan – Boltzmann Constant \( \sigma = 5.67 \times 10^{-8} \) \( \text{W/m}^2\text{K}^4 \)

• 1 gallon = 3.8 L.

• Energy Density of Gasoline: \( 3 \times 10^7 \) J/L