Thermal Energy Transmission - Radiation

- Wavelength and frequency
- Wien’s Law
- Power/Intensity
Electro-magnetic waves

Velocity = \frac{\text{How far you go}}{\text{How long it took you}} = \frac{\text{Wavelength}}{\text{Period}} = \frac{\lambda}{T} \quad v = f \cdot \lambda
Example 5.1 Wave Length

The frequency of the country music station “US 99” is 99.5 MHz (99.5 \times 10^6 \text{ cycles/sec}). What is the wavelength of its radio wave?

The frequency of blue visible light is around 620 \times 10^{12} \text{ Hz}. What is the wavelength of its radio wave?

Remember! All electromagnetic waves have the same speed!
\[ v = c = 3 \times 10^8 \text{ m/sec} \]
Longer waves

Higher frequency

Enough energy to damage cells

60 Hz $\lambda = 5 \times 10^6 \text{m}$

Thermal Radiation – Unit 05, Slide 4
How much energy via radiation?

**Stefan’s constant**

\[ \text{Power} = \sigma \varepsilon \text{Area} T^4 \]

**Heat per time (Watts)**

**Emissivity**

**Stefan-Boltzmann’s Law**

\[ \sigma = 5.67 \times 10^{-8} \text{ W/(m}^2\text{-K}^4) \]

\[ \varepsilon \rightarrow \text{amount absorbed (1 for black)} \]
Everything Emits Radiation!

As long as $T \neq 0$!
Example 5.2: Power from the sun

What is the rate of energy released from the sun via radiation?

- \( T_{\text{sun}} = 5887 \text{K} \)
- \( \varepsilon_{\text{sun}} \sim 1 \)
- \( r_{\text{sun}} = 7 \times 10^8 \text{m} \)

\[
P = \sigma \varepsilon \text{Area} T^4
\]

Surface area of Sphere = \( 4\pi r^2 \) (on formula sheet)
Example 5.3: Temperature of the Earth

We just calculated that the sun puts out $4.14 \times 10^{26}$ Watt of power via radiation.

How much of that power hits the earth?

The radius of the earth is $r_{\text{earth}} = 6.4 \times 10^6$ m. The earth is $r_{\text{orbit}} = 1.5 \times 10^{11}$ m from the sun.

A) $1.9 \times 10^{17}$ Watts
B) $0.9 \times 10^{17}$ Watts
C) $2.4 \times 10^{12}$ Watts
D) $3.4 \times 10^{11}$ Watts

$P = \sigma \varepsilon A T^4$
Example 5.3: Temperature of the Earth

We just calculated that $1.9 \times 10^{17}$ Watts of power hits the earth via radiation. 30% is reflected by the atmosphere, so the earth absorbs

$$1.3 \times 10^{17} \text{ Watts}$$

If the same amount of power must leave the earth, what should the temperature of the earth be?

A) 410K  
B) 350K  
C) 260K  
D) 150K

Surface area of Sphere = $4\pi r^2$  
(on formula sheet)

$$P = \sigma \varepsilon T^4$$

$\varepsilon_{\text{earth}} \sim 1$, $r_{\text{earth}} = 6.4 \times 10^6 \text{m}$
Why is earth not freezing all the time?

Wien’s Law – $\lambda_{\text{peak}}$ depends on $T$

$$\lambda_{\text{peak}} = \frac{2.9 \text{mm}K}{T}$$

- $\lambda_{\text{out}}$ is longer than $\lambda_{\text{in}}$
- $\varepsilon_{\text{earth}}$ is smaller for longer $\lambda$
- “Green house effect”
Example 5.4: Peak $\lambda$

The temperature of the sun is 5887K.

What is the peak wave length, $\lambda_{\text{peak}}$, of the radiation beginning transmitted?

What is its frequency of the wave, $f$?

What is the period of the wave, $T$?

What is the velocity of the wave?

\textit{Easy!} All electromagnetic waves have the same speed $v=c=3\times10^8 \text{ m/sec}$.
Longer waves

Higher frequency

Enough energy to damage cells

Thermal Radiation – Unit 05, Slide
Wien’s Law

\[ u(\lambda) \text{ [kJ/nm]} \]

\[ \lambda \text{ [nm]} \]

- \( T = 5500K \)
- \( T = 5000K \)
- \( T = 4500K \)
- \( T = 4000K \)
- \( T = 3500K \)
The temperature of the earth is around 287K.

What is the peak wave length of the radiation beginning transmitted?
Higher frequency

Longer waves

Enough energy to damage cells

Thermal Radiation – Unit 05, Slide 15
We just determined that the peak wave length of the electromagnetic waves coming from the earth peaks at around 4.9\(\mu\)m.

What is the velocity of this wave?

A) 4.9 m/sec  
B) 4.9 \(\mu\)m/sec  
C) 3\(\times\)10\(^8\) m/sec  
D) 4.9 \(\times\) 10\(^8\) m/sec  
E) 1/4.9 \(\mu\)m/sec
Do you emit light?

The temperature of your skin is around 98.6°F. What is the peak wave length of the radiation you transmit?
The temperature of your skin is around 98.6°F. What is the temperature of your skin in Kelvins?

A) 0K
B) 98.6K
C) 37K
D) 310K
E) 522K
The temperature of your skin is around 98.6° F. What is the peak wavelength of the light you emit?

A) $2.9 \times 10^{-3}$ m
B) $2.9 \times 10^{-6}$ m
C) $3.1 \times 10^{-6}$ m
D) $6.2 \times 10^{-6}$ m
E) $9.4 \times 10^{-6}$ m
Longer waves

Higher frequency

Enough energy to damage cells
Look for heat losses?
Heat Loss at my house
Older Window (double pane)

Colder at center

Modern Window (triple pane)

Colder at frame
Embarrassing item #1

8” of concrete (e.g. uninsulated basement wall) has $R \sim 1.35$

Brand new zillion dollar window

Exposed concrete basement wall

$R \sim 5.1$

$R \sim 1.35$
2” of wood (e.g. uninsulated band board + siding) has $R \sim 2.2$

(Exterior Shot)

- Really BIG brand new zillion dollar window 
  $R \sim 5.1$

- Insulated Wall 
  $R \sim 13$

- 2”X10” Bandboard + siding 
  $R \sim 2.2$

- Exposed concrete basement wall 
  $R \sim 1.35$
Embarrassing item #3

A wood-on-wood connection makes a very poor air seal

(Note: Photos taken during 5Pa vacuum air tightness test)

Cold air pouring into basement at joint between band board and foundation wall

Cold air pouring into kitchen at joint between wall frame and floor
Embarrassing item #4

Insulation doesn’t always stay where you put it and in the condition you put it there

New insulation fell during sheetrock installation?

Insulation damaged by past water leak