Learning Goals:

• Qualitatively describe the spectrum of thermal radiation and how this depends on temperature.
• Determine the temperature of an object using the peak wavelength for its thermal radiation.
• Predict the total power of radiation from an object given its temperature, surface area, and emissivity.
• Explain why the emissivity of an object is higher for objects that are better absorbers.
• Argue that for a system whose temperatures are not changing, the heat current into any part equals the heat current out of that part.
• Predict the surface temperature of an object given the heat current absorbed and/or heat currents from the interior.
Last time in Physics 157

Infrared radiation

Oscillating electric and magnetic fields

$3 \times 10^8 \text{ m/s}$
Radiation from an object comes in a mix of wavelengths. We can describe this by graphing the spectrum.

Area gives total power in the indicated range of wavelengths.
Which graph best represents the spectrum of radiation from the red hot ball in the picture?

A) 

B) 

C)
Which graph best represents the spectrum of radiation from the red hot ball in the picture?

A)  

B)  

C)  See simulation

From YouTube: 1000 Degree Metal Ball vs Milk
In the simulation, what properties of the thermal spectrum change as we change the temperature?
Peak wavelength is inversely proportional to $T$

$\lambda_{\text{max}} = \frac{b}{T}$

Wien displacement law

- **Sun**: peak at $\approx 500\text{nm}$ → $5700\text{K}$
- **Outer Space**: peak at $1\text{mm}$ → $2.7\text{K}$

"Cosmic Microwave Background"
**Orange Star**

\[ T \approx 4500K \]

**Blue Star**

\[ T \approx 12,000K \]
Total power is proportional to $T^4$

$$H = A \cdot e \cdot \sigma \cdot T^4$$

- $H$: heat current
- $A$: surface area
- $e$: emissivity
- $\sigma$: Stefan-Boltzmann constant
- $5.67 \times 10^8 \frac{W}{m^2 \cdot K^4}$
A white object and a black object both sit in an oven. The oven and the objects are in equilibrium at 1500 degrees Celsius. We can say that the net heat current from radiation, \((H_{\text{absorbed}} - H_{\text{emitted}})\) is

A) Larger for the white object  
B) Larger for the black object  
C) The same for both objects and greater than zero.  
D) The same for both objects and equal to zero.  
E) The same for both objects and less than zero.

Assume that there are no conduction or convection effects.

**EXTRA:** Which object is emitting more radiation?
A white object and a black object both sit in an oven. The oven and the objects are in equilibrium at 1500 degrees Celsius. We can say that the net heat current from radiation, \((H_{\text{absorbed}} - H_{\text{emitted}})\) is

\[
\text{Equilibrium} \Rightarrow \text{const. } T \\
\Rightarrow \text{no net heat current}
\]

\[\therefore H_{\text{absorbed}} - H_{\text{emitted}} = 0\]

A) Larger for the white object  
B) Larger for the black object  
C) The same for both objects and greater than zero.  
D) The same for both objects and equal to zero.  
E) The same for both objects and less than zero.

Assume that there is no air in the oven and the objects are insulated from the walls so there is no conduction or convection.
A white object and a black object both sit in an oven. The oven and the objects are in equilibrium at 1500 degrees Celsius. We can say that the net heat current from radiation, \((H_{\text{absorbed}} - H_{\text{emitted}})\) is

\[
H_{\text{emitted}} = H_{\text{absorbed}}
\]

\[\uparrow\]

larger for black object

\[
\therefore \text{black object radiates more!}
\]
**Emissivity:**

- Perfect absorber = "blackbody" emits the most thermal radiation for a given temperature.

- Other objects: define

\[ e = \frac{H}{H_{\text{blackbody}}} \]

\[ e = 1 \text{ blackbody} \quad e = 0 \text{ perfect mirror} \]
Total Power from Thermal Radiation

\[ H = A \cdot e \cdot \sigma \cdot T^4 \]

- **Heat Current**
- **Surface Area**
- **Emissivity**
  - \( e = 1 \): Perfect absorber (black)
  - \( e = 0 \): Perfect reflector (mirror)

Stefan-Boltzmann constant: \( 5.67 \times 10^{-8} \, \text{W/m}^2 \cdot \text{K}^4 \)
NET HEAT CURRENT FROM THERMAL RADIATION
(in uniform temperature environment)

Surface area

\[ H = A \cdot e \cdot \sigma \cdot (T^4 - T_s^4) \]

- \( e = 1 \) perfect absorber (black)
- \( e = 0 \) perfect reflector (mirror)

Stefan-Boltzmann constant
\( 5.67 \times 10^8 \text{ } \frac{\text{W}}{\text{m}^2 \cdot \text{K}^4} \)

temp. of surroundings

T_s
Yoltar heats their little planet (far from any stars) with a 1GW heater. If they wish to double the equilibrium surface temperature of their planet, they should increase the power of their heater to

A) 1.21GW  
B) 2GW  
C) 4GW  
D) 8GW  
E) 16GW

Hint: where does the energy from the heater go?
Steady state:
Power from heater = power radiated

\[ P_{\text{heater}} = A \cdot \sigma \cdot e \cdot T^4 \]

To double \( T \)
Need \( 16 \times P \)
A planet with radius $r = 6400\text{km}$ lies at a distance $R = 150,000,000\text{km}$ from a yellow star with temperature $T = 5700\text{K}$ and radius $R_S = 695,000\text{km}$. Estimate the surface temperature of the planet.

The planet has albedo (fraction of incident light reflected) $A = 0.37$ and emissivity $e$ close to 1.

A harder (but really interesting!) problem.

NEXT TIME