8.3 Temperature and Heat

Heat Transfer
- Conduction
- Convection
- Radiation
- Thermal Energy Balance

Heat Flow

Heat flows from high temperature to low temperature. The rate of heat flow depends on the thermal connection between the two systems.

Conduction

Heat flow is negative out of the region of high temperature.

\[ H = -k \frac{dT}{dx} \]

- \( k \) = thermal conductivity (W/m•K)

Mechanisms of heat transfer

- Conduction: important for short distances, depends on the material through which heat flow occurs.
- Convection: involves the movement of heated mass, more efficient than conduction for long distances.
- Radiation: occurs even through a vacuum, depends on the properties of the radiating surface.

Thermal conductivities

<table>
<thead>
<tr>
<th>Material</th>
<th>Si Unit W/m•K</th>
<th>British Units BTU•in/h•ft•°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.026</td>
<td>0.18</td>
</tr>
<tr>
<td>Wood (pine)</td>
<td>0.11</td>
<td>0.78</td>
</tr>
<tr>
<td>Aluminum</td>
<td>237</td>
<td>1644</td>
</tr>
<tr>
<td>Glass</td>
<td>0.7-0.9</td>
<td>5-6</td>
</tr>
<tr>
<td>Goose down</td>
<td>0.046</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Question
Find the heat flow through a 1.0 m² styrofoam slab 2.0 cm thick with a temperature gradient of 10°C (k_{styrofoam}=0.029 W/m·K)

Heat conduction through 2 slabs in series.

The overall temperature difference is \(T_3 - T_1\).
The temperature at the interface between the two slabs is \(T_2\). Where \(T_1 < T_2 < T_3\) and

Thermal Resistance
\[
R = \frac{\Delta x}{kA}
\]

Heat Flow
\[
H = \frac{T_3 - T_1}{R_1} + \frac{T_2 - T_1}{R_2}
\]
Eliminate \(T_2\)
\[
H = \frac{T_3 - T_1}{\frac{1}{R_1} + \frac{1}{R_2}}
\]
(resembles Ohm’s Law)
The total R is the sum of Rs Like Ohm’s Law for 2 resistor in series.

R-factor

The R factor is an insulation parameter that is independent of area. It only depends on the material
\[
\mathfrak{R} = RA = \frac{\Delta x}{k}
\]
The Unit of \(\mathfrak{R}\) are usually in British units ft²°Fh/BTU
\(\mathfrak{R}-11\) fiberglass insulation means \(\mathfrak{R} = 11\) ft²°Fh/BTU

Question
A storage shed is made out of two layers of plywood each \(\mathfrak{R}=0.65\), and a layer of \(\mathfrak{R}-11\) fiberglass. The total area of the shed is 1200 ft². If the shed is heated to a temperature of 65°F when the outside temperature is 40°F. How much does it cost per month to heat the shed with gas at the price of $1.20 per therm (1 therm=105 BTU)

Convection

Convection involves movement of fluid carrying heat
Convection is more efficient than conduction over long distances.

Convection Oven

Convection involves the movement of fluid carrying heat, which is more efficient than conduction for long distances.
Gulf stream
Warm water from the Gulf of Mexico warms Europe.

Thermal Radiation
- All objects emit electromagnetic radiation
- The radiation propagates in a vacuum.
- The radiated power increases with temperature to the 4th power, $T^4$
- The spectrum of thermal radiation changes with temperature.

Ideal Black-body radiation
Consider an enclosed box at a temperature $T$.
The radiation in the box is in thermal equilibrium with the walls at a temperature $T$.
If we cut a hole in the box the light from the hole will be blackbody radiation.

Spectrum of Black body radiation
Wein’s displacement Law
$T\lambda_{max}=\text{constant}=2.90\times10^6 \text{ nm K}$
Peak wavelength decreases at higher $T$.

Power
The power output of thermal radiation is given by the Stefan-Boltzmann law
$$P = e\sigma T^4$$
$\sigma$ = Stephan-Boltzmann constant = $5.67\times10^{-8} \text{ W/m}^2\text{K}^4$
e = emissivity a parameter with values from 0-1
e=1 is a perfect emitter and perfect absorber of radiation ideal “black body”.
e=0 does not emit or absorb radiation.

Thermal radiation balance.
Radiative heat flow depends on temperature of object and temperature of the surroundings $T_o$.
$$p_{net} = e\sigma T^4 - e\sigma T_o^4$$
Question
An unclothed person with a skin temperature of 34° C with a surface area of 2.0 m and has a basal metabolism generating heat at a rate of 140 W. What would be the room temperature at which the there would be no net increase in body temperature. (assume e =1.0)

Find the temperature of the earth determined by the energy balance between radiation absorbed and emitted.

\[
\text{Intensity at the earth's surface } I = 960 \text{ W/m}^2
\]

\[
\text{Power output (blackbody at temperature } T) = e A \sigma T^4 = e A \pi R_e^2 \sigma T^4
\]

\[
\text{Power input } P = A I R
\]

\[
T = \left( \frac{1}{4e} \right)^{1/4} \frac{I}{\pi R_e^2 \sigma T^4} = 255K \approx -18^\circ C
\]

Close but too low

Blackbody radiation from the earth.

Earth is a blackbody near 300 K
Spectrum is shifted to longer wavelengths
From Wein Law
\[
T_\lambda = \text{constant }
\]

30% reflected

CO₂, water, methane, ozone

Sunlight

Atmospheric gases

Infrared radiation

The atmosphere absorbs infrared radiation to warm the surface of the earth.

Greenhouse gas

Global Warming

Too much absorption by the atmosphere causes warming

The rise in global temperature is correlated with the rise in CO₂ in the atmosphere.