L 18 Thermodynamics [3]

- Heat transfer processes
  - convection
  - conduction
  - radiation
- Thermodynamics of the atmosphere
  - Greenhouse effect and climate change
  - Effect of the ozone layer

Convection
- heat is transferred from one location to another by the bulk movement and mixing of liquids or gases (fluids)
- Convection does NOT occur in solids
- when water is boiled, hot water at the bottom rises and mixes with cooler water at the top
- Hot air rises:
  - want heated air into lower level of house in the winter
  - cooled air into upper levels in the summer

Conduction
- heat is transferred directly through a material, with no bulk movement of material
- only energy moves (molecules in a solid are not free to move, but can vibrate)
- iron is a particularly poor conductor of heat

Heat flow rate depends on $A / L$ and a property unique to the material, called thermal conductivity

Thermal Conductivity: a parameter that quantifies the ability of a material to conducting heat.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>metals</td>
<td>14 - 400</td>
</tr>
<tr>
<td>wood</td>
<td>0.15</td>
</tr>
<tr>
<td>glass</td>
<td>0.8</td>
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<tr>
<td>wool</td>
<td>0.04</td>
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<tr>
<td>Goose down</td>
<td>0.025</td>
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<tr>
<td>Styrofoam</td>
<td>0.01</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Metal</th>
<th>Thermal Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>406</td>
</tr>
<tr>
<td>Copper</td>
<td>385</td>
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<tr>
<td>Aluminum</td>
<td>205</td>
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<td>Brass</td>
<td>109</td>
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<tr>
<td>Iron</td>
<td>80</td>
</tr>
<tr>
<td>Steel /SS</td>
<td>50/14</td>
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</table>

Heat as moving light $\rightarrow$ radiation

- Radiation is the heat transfer by electromagnetic waves – thermal light waves - invisible to the eyes
- thermal radiation is a small part of the electromagnetic spectrum – waves are characterized by their frequency or wavelength
- different colors in the visible correspond to different wavelengths from red to blue
**Electromagnetic Spectrum**

- TV
- Microwaves, cell phones
- Thermal radiation
- Radio waves
- Visible light
- X-rays
- Electromagnetic waves: LIGHT
  - Shorter wavelength → more energy
  - Thermal radiation
  - Visible light
  - UV radiation produces sunburn

**Thermal Radiation**

- The warmth you feel from the sun is the sun’s thermal radiation.
- It travels through the vacuum of space to reach earth, no material is necessary (takes 8 minutes).
- You can feel its effects even though you cannot see the radiation.
- You can feel the thermal radiation from a fireplace.
- Objects not in contact with liquids gases or other solids loose heat by radiation.

**What produces thermal radiation?**

- All objects whose temperature is above absolute zero emit thermal radiation.
- The hotter the object, the more radiation it emits, the amount of radiation is $\sim T^4$.
- We all continuously emit thermal radiation.
- We also absorb it from objects and people around us.
- If we just emitted radiation we would eventually cool to absolute zero!

**Emission and Absorption are balanced**

**Thermal radiation spectrum**

- The intensity of radiation increases with temperature.
- The color shifts toward the blue at higher temperatures.
- The UV radiation from the sun is just beyond the violet (11,000 F).
sources of thermal radiation

- the incandescent light bulb (the ones that have a filament) are sources of both visible light and heat.
- when electricity flows through a wire it gets hot.
- it emits radiation even though you can't see it.
- as it gets hotter it glows red then orange then white.

good emitters are good absorbers

- an object that is a good emitter is also a good absorber of thermal radiation.
- a poor emitter is also a poor absorber.
- generally dark, dull objects are the best emitters/absorbers.
- shiny objects are poor emitters/absorbers, they are good reflectors of radiation.
- If you do not want the edges of your pie to burn, you wrap it in aluminum foil. The aluminum foil reflects the heat rather than absorbing it.

good/bad emitters—Leslie’s cube

- copper cube filled with hot water
- this side is painted black
- infrared radiation sensor

Practical considerations

- wear light clothing in summer → light clothing absorbs less sunlight.
- cover all body parts in winter → warm body parts (like your head) emit radiation.

Which thermos bottle is best?

A. silvered
B. silvered and un-evacuated
C. evacuated
D. un-silvered and un-evacuated

Why is it colder at the poles than at the equator?

- More of the Sun’s energy per unit area falls on the equatorial regions compared to the polar regions.
- the earth reflects about 30% of incident solar energy.
- without the atmosphere the earth would be 30°C cooler!
- Seasons are due to change in tilt of the earth.
The Greenhouse effect

Sun’s visible light
infrared radiation

$\text{CO}_2, \text{H}_2\text{O}$

Without the greenhouse effect, the average temperature of the Earth would be $-20^\circ F$.

Effect of greenhouse gases: $\text{H}_2\text{O}, \text{CO}_2, \text{CH}_4, \ldots$

- the sun’s visible light can penetrate through the atmosphere to the earth’s surface where it heats it
- the visible light energy is converted to thermal light energy
- the thermal radiation is reflected from the greenhouse gases in the atmosphere
- $\text{CO}_2$ concentrations are about 0.04% and increasing
- Water vapor accounts for up to 66%

Greenhouse effect Demo

Heat source
Wooden box with glass window

glass lets visible light through, but blocks infrared heat rays from getting out

Temperature change 1880-2003

What are climate forcings?

- The climate of the Earth is affected by a number of factors
- These factors are called "forcings" because they drive or "force" the climate system to change
- The forcings that were probably the most important during the last millennium were:
  - changes in the output of energy from the sun
  - volcanic eruptions (injects dust into the atm.)
  - changes in the concentration of greenhouse gases in the atmosphere
    (natural vs. anthropogenic ? ? ?)

Climate change issues

- Are climate changes part of a natural cycle?
- What is the effect of human activity (anthropogenic) on the buildup of greenhouse gases?
- (NRC 2001) Because of the large and still uncertain level of natural variability inherent in the climate record and the uncertainties in the time histories of the various forcing agents (and particularly $\text{SO}_2$), a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate changes during the 20th century cannot be unequivocally established.
- The IPCC (International Panel on Climate Change) 2/2/07: "global warming is "very likely" caused by man.
- 2010- recent revelations have cast some doubts on methods used to acquire and analyze data on climate change
- What are the economic repercussions of taking or not taking strong measures to curb greenhouse emissions?
Greenhouse effect and climate change

- concentrations of CO$_2$ have been increasing
- $\Rightarrow$ rise in earth’s temperature
- similar effect occurs in your car during the day.

The ozone layer: blocks solar ultraviolet radiation

- ozone, O$_3$ is a naturally occurring trace element in the atmosphere
- It absorbs solar ultraviolet radiation, especially the harmful UV-B rays
- it is destroyed by CFC’s (chlorofluorocarbons)
- loss affects us and environment