Heat transfer (very applicable for today)

Goals for this session

1. To talk about three basic mechanisms of heat transfer (conduction, convection, and radiation).

2. To answer any questions you might have about the worksheets or the WebAssign assignment.

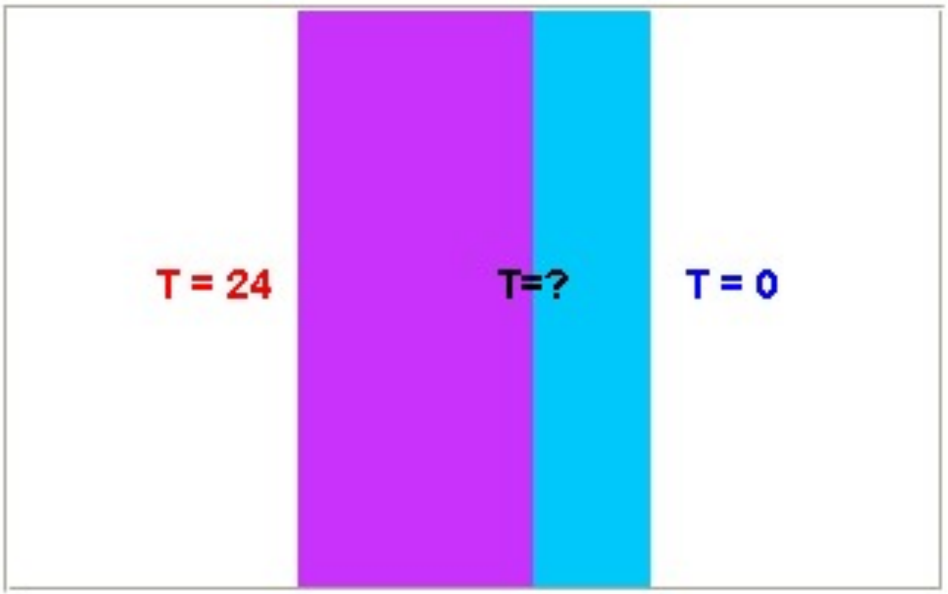
3. To have a discussion about the readings.

Reminder - the mid-term test will be handed out at the next session. We're planning to give it as a take-home test, so we don't lose valuable class time - let us know if you object to that!

A conduction sandwich

A typical conduction problem involves creating a sandwich of two (or more) layers and determining the temperature at the interface(s) between the layers.

Consider a two-layer problem where one layer has twice the thickness and six times the thermal conductivity as the other layer, but the layers have the same area.



A conduction sandwich

To find the temperature at the interface between the layers (after thermal equilibrium has been reached) you should:

1. find that the unknown temperature is halfway between the temperature on one side and the temperature on the other side (T = ?)

2. set up a ratio where the change in temperature across a layer is proportional to the thickness of the layer (T = ?)

3. set up a ratio where the change in temperature across a layer is inversely proportional to the thickness of the layer (T = ?)

4. set the rate of heat flow through one layer equal to the rate of heat flow through the other layer (T = ?)

A conduction sandwich

To find the temperature at the interface between the layers (after thermal equilibrium has been reached) you should:

1. find that the unknown temperature is halfway between the temperature on one side and the temperature on the other side (T = 12° C)

2. set up a ratio where the change in temperature across a layer is proportional to the thickness of the layer (T = 8° C)

3. set up a ratio where the change in temperature across a layer is inversely proportional to the thickness of the layer (T = 16° C)

4. set the rate of heat flow through one layer equal to the rate of heat flow through the other layer (T = 18° C)

Convection

Heat transfer in fluids generally takes place via convection, in which flowing fluid carries heat from one place to another. Convection currents are produced by temperature differences. Hotter (less dense) parts of the fluid rise, while cooler (more dense) areas sink. Birds and gliders make use of upward convection currents to rise, and we also rely on convection to remove ground-level pollution.

Forced convection, where the fluid does not flow of its own accord but is pushed, is often used for heating (e.g., forced-air furnaces) or cooling (e.g., fans, automobile cooling systems).

Thermal radiation

Thermal radiation involves energy transferred via electromagnetic waves. Often this is infrared radiation, but it can also be visible light or radiation of higher energy.

Thermal radiation is relatively safe, and is not the dangerous nuclear radiation associated with nuclear bombs, etc.

All objects continually absorb thermal energy and radiate it away again. When everything is at the same temperature, the amount of energy received is equal to the amount given off and no changes in temperature occur. If an object emits more than it absorbs, though, it cools down.

Thermal radiation

For an object with a temperature *T* (in Kelvin) and a surface area *A*, the net rate of radiated energy depends strongly on temperature:

$$P_{net} = P_{radiated} - P_{absorbed} = \sigma e A(T^4 - T_{env}^4)$$

where T_{env} is the temperature of the surrounding environment, and the Stefan-Boltzmann constant is

$\sigma = 5.67 \times 10^{-8}$ W/m^2

e is the emissivity, a measure of how efficiently an object absorbs and emits radiated energy. Highly reflective objects have emissivities close to zero. Black objects have emissivities close to 1. An object with *e* = 1 is called a perfect blackbody.

Thermal radiation

The best absorbers are also the best emitters. Black objects heat up faster than shiny ones, but they cool down faster too.

This is exactly what we observe with our black can and white can, as the cans cool.

Newton's Law of Cooling

In many situations (and our cans are an example of this), the temperature of a hot object that is cooling follows an exponential decay. What does this tell us about what the rate at which the object loses energy? How does this rate of energy loss depend on temperature?

Exponential decay is characteristic of a rate that is proportional to a quantity, in this case the temperature difference between the object and the surroundings.

$$\frac{dQ}{dt} = hA(T_{object} - T_{env})$$

h is the heat transfer coefficient

Newton's Law of Cooling

With the rate of energy loss being proportional to the temperature difference, the exponential equation for the temperature of the object as a function of time is

$$T_{object} = T_{env} + (T_{initial} - T_{env})e^{-\lambda t}$$

λ is the decay rate, which depends on the surface area and emissivity.