8.3 Temperature and Heat

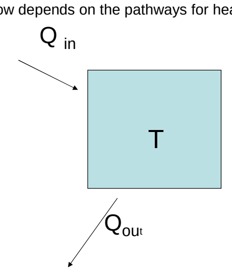
Heat Transfer
- Conduction
- Convection
- Radiation

Thermal Energy Balance

Heat Transfer

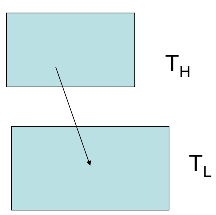
The temperature of an object depends on the input and output of thermal energy

The rate of heat flow depends on the pathways for heat transfer.



Heat Flow

$$H = \frac{dQ}{dt}$$

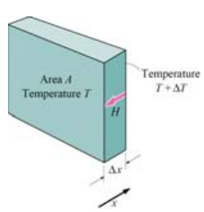


Heat flows from High temperature to low temperature
The rate of heat flow depends on the thermal connection between the two systems.

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.

Conduction



Heat flow is negative out of the region of high temperature

$$H = -kA\frac{\Delta T}{\Delta x}$$

The minus sign means that flow is opposite to the direction of increasing T

k = thermal conductivity W/m•K

Thermal conductivities

Material	SI Unit W/m•K	British Units BTU•in/h•ft^2•^{o}F
Air	0.026	0.18
Wood (pine)	0.11	0.78
Aluminum	237	1644
Glass	0.7-0.9	5-6
Goose down	0.046	0.30

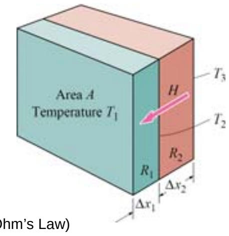
Question

Find the heat flow through a 1.0 m^2 styrofoam slab 2.0 cm thick with a temperature gradient of 10^o 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

$$H = -\frac{T_3 - T_2}{R_2} = -\frac{T_2 - T_1}{R_1}$$

(resembles Ohm's Law)

Eliminate T_2

$$H = \frac{T_1 - T_3}{R_1 + R_2} = \frac{T_1 - T_3}{R_{total}}$$

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

$$\Re = RA = \frac{\Delta x}{k}$$

The Unit of $\Re$ are usually in British units $ft^2\,^oFh/BTU$

$\Re$-11 fiberglass insulation means $\Re$ = 11 $ft^2\,^oFh/BTU$

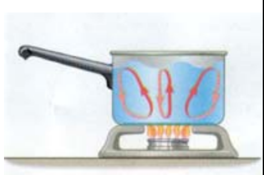
Question

A storage shed is made out of two layers of plywood each $\Re$=0.65, and a layer of $\Re$-11 fiberglass. The total area of the shed is 1200 ft^2. If the shed is heated to a temperature of 65^{o}F when the outside temperature is 40^{o}F. How much does it cost per month to heat the shed with gas at the price of \$1.20 per therm (1 therm=10^5BTU)

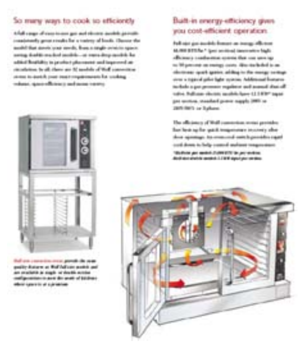
Convection

Convection involves movement of fluid carrying heat

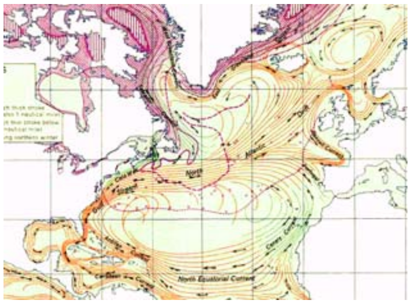
Convection is more efficient than conduction over long distances.



Convection Oven



Gulf stream

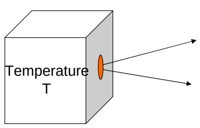


Warm water from the Gulf of Mexico warms Europe.

Thermal Radiation

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

Ideal Black-body radiation



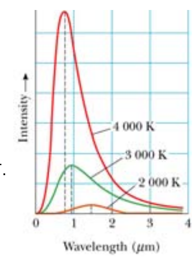
Consider an enclosed box at a temperature T
The radiation in the box is in thermal equilibrium with the walls at a temperature T.
If we cut a hole in the box the light from the hole will be blackbody radiation

Spectrum of Black body radiation

Wein's displacement Law

$T\lambda_{max}$= constant =2.90×10^6 nm K

Peak wavelength decreases at higher T.



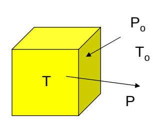
Power

The power output of thermal radiation is given by the Stefan-Boltzmann law

$$P = e\sigma AT^4$$

σ= Stephan-Boltzmann constant =5.67×10^{-8} W/m^2•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.



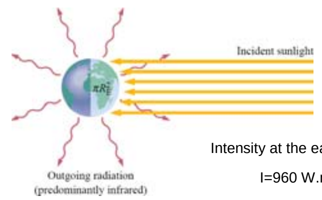
Radiative heat flow depends on temperature of object and temperature of the surroundings T_o.

$$p_{net} = e\sigma AT^4 - e\sigma AT_o^4$$

Question

An unclothed person with a skin temperature of 34º 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.



Intensity at the earth's surface

I=960 W.m²

Power output (blackbody at temperature T)

$P = eA\sigma T^4 = e4\pi R_E^2\sigma T^4$

Power input

$P = AI = \pi R_E^2 I$

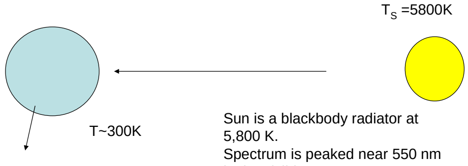
Close but too low

Solve for T

$$T = \left(\frac{I}{4e\sigma}\right)^{1/4} = \left(\frac{960\,W/m^2}{4(1)5.67x10^{-8}\,W/m^2K^4}\right)^{1/4} = 255K = -18^\circ C$$

Blackbody radiation from the earth.

T_S =5800K



T~300K

Sun is a blackbody radiator at 5,800 K.
Spectrum is peaked near 550 nm in the visible.

Earth is a blackbody near 300 K
Spectrum is shifted to longer wavelengths

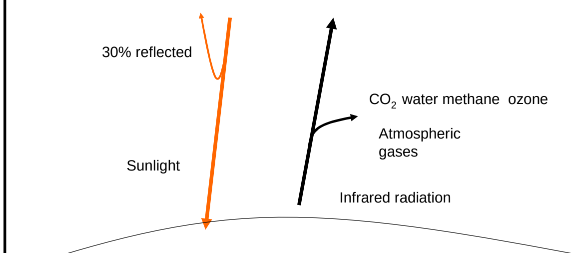
From Wein Law

$T\lambda_{max}$ = constant

$$\lambda_E = \left(\frac{T_S}{T_E}\right)\lambda_S = \frac{5800}{300}550nm = 1.06x10^4 nm = 10\mu m$$

In the infrared region

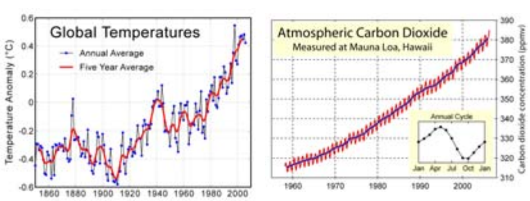
Greenhouse gas



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

Global Warming

Too much absorption by the atmosphere causes warming



The rise in global temperature is correlated with the rise in CO_2 in the atmosphere.