Lec #9: Thermal Energy II. (Chaps. 4 & 5)

LAST TIME: Thermal Energy I.

- Internal Kinetic and Potential Energy
- Temperature and Heat
- Laws of Thermodynamics
- Specific Heat

TODAY: Thermal Energy. II.

- Phase Transitions
- Conduction, Convection, Radiation
- Thermodynamic Efficiency & Heat Engines

NEXT WEEK: Electricity and Magnetism

- skip to Chapters 10 & 11 (Electromagnetism)

Phase Transitions

T increasing ------> <----- P increasing

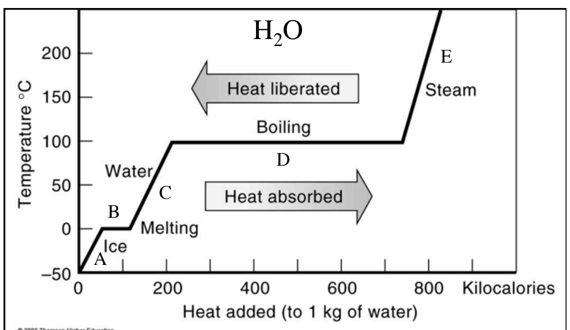
SOLID LIQUID GAS PLASMA

melt-> *vaporize->* *ionize->*

<-fuse *<-condense* *<-recombine*

- generally, $Q=mc\Delta T$
  - c_s = "specific heat" ; m=mass
  - can be different for same material in diferent phases (e.g. H_2O solid 0.5, liquid 1.0, gas 0.48)
- *during* phase transition, Q=mL
  - L = "latent heat"
  - no change in temperature! (where does energy go?)

H_2O



A) c = 2090 J/(kg K) C) c = 4190 J/(kg K) E) c=2010 J/(kg K)

B) L_f = 333000 J/kg D) L_v = 2260000 J/kg

Ideal Gas Law

- Pressure = |**Force**| /Area (not a vector)
- "ideal gas": energy exchange dominated by elastic collisions

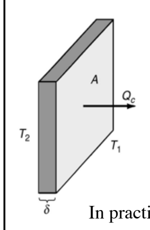
  equation of state:

  Pressure * Volume = k * Temperature
  - k= Boltzman's constant
  - or P=nkT where n = gas density (#/volume)
- solids and liquids (and some gasses) have different equations of state; related to potential energy of bonds, elasticity of collisions, etc.

How is Thermal Energy Transferred?

- *Net transfer* of thermal energy (i.e. "Heat") only when there is a *temperature difference*, and always in direction of higher to lower T.
- There are really only 2 fundamental ways. Both are electromagnetic phenomena (collisions and radiation).
- We'll talk about 3 ways:
  - "conduction" (physical contact)
  - "convection" (motion of material)
  - "radiation" (action at distance; photon exchange)

Conduction



$$\frac{Q_c}{t} = \frac{k \times A \times (T_2 - T_1)}{\delta}$$

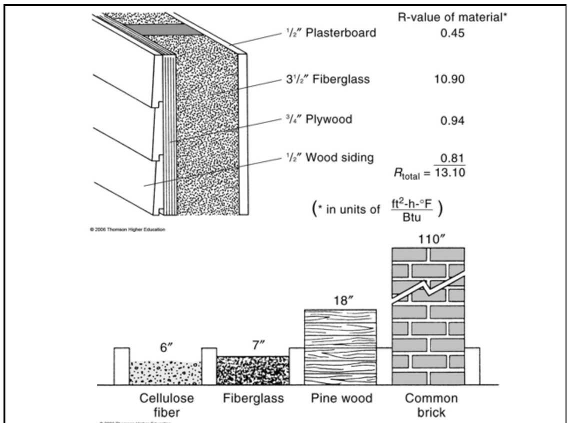
- k = thermal conductivity (depends on material)
- A = area
- δ = thickness
- Q/t = energy / time = H

In practice, instead of k, we use "R values"

$$H = A\,(T_2 - T_1) / \Sigma R_i$$

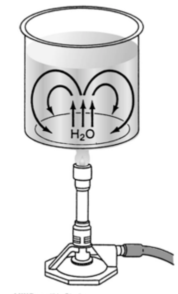
units of R: (ft^2 °F h)/BTU

except for air (which depends on wind speed, etc.), we can look these up in a table (e.g. Table 5.2 in your text) ...



Convection

- transport of warm material to region of colder material
- usually a cyclic process
- e.g. boiling water
- e.g. our atmosphere



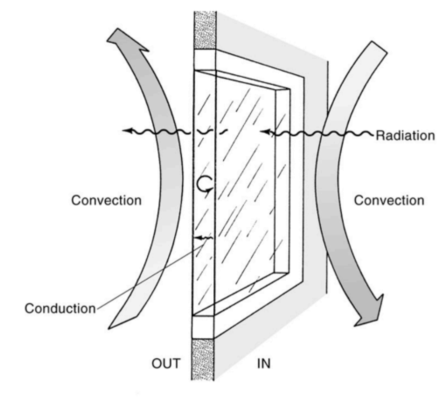
stratosphere	T increases w/ height (ozone layer)
troposphere	T decreases w/ height

(ground)

stratosphere: stable; troposphere: turbulence, thunderstorms, etc.

"Electromagnetic" Radiation

- no medium is required (goes through vacuum!)
- action at a distance
- emission $\propto T^4$ (2x temp = 16 times the energy flow)
- emission and absorption balanced in thermal equilibrium (and balanced with collisions)
- radio, infrared, visual, ultraviolet, x-ray, γ-ray are all forms of emr
- what we perceive as "heat" is often infrared



How Do We Minimize Heat Transfer?

- Conduction $Q/t = k\,A\,\Delta T / \delta = A\,\Delta T / \sum R_i$
  - minimize conductivity (insulating materials)
  - lower surface area
  - thicker wall
  - lower ΔT
- Convection $Q/t \sim$ velocity and ΔT
  - stop air currents (or use them to advantage)
  - vacuum works great; still air pretty good, too
- Radiation $Q/t = A\,\sigma\,T^4$
  - reflect infrared with shiny materials

  e.g. "Dewar flask"

Thermodynamic Efficiency

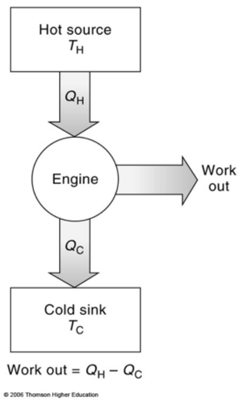
Efficiency = 100%x(useful energy out)/(available energy)

- What is "useful" energy (or work) out?
- What is "available" energy in?
- For a heat engine, useful work out is always *less than* the available energy input

Maximum ("Carnot") efficiency:

Maximum Efficiency = 100% x $(T_H - T_C) / T_H$

- caution: must use absolute temperature scale!
- $T_H > T_C$ so ratio is always <1



Examples:

T_H	T_C	η
1000	373	63%
813	293	64%
4000	300	93%
OTEC...25 C	5 C	6%

but what happens at 4000 degrees?

how low can T_C go?

how high can T_H go?

Energy Conversion Efficiency

- Efficiency = 100% x
  (useful energy out) / (available energy in)
- seldom, if ever, 100%
- Net efficiency = **product** of individual efficiencies
- Chain that is weaker than its weakest link!

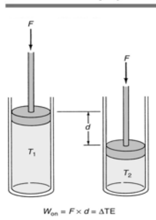
Table 3.1 EFFICIENCIES OF SOME ENERGY CONVERSION DEVICES AND SYSTEMS

Device	Efficiency
Electric generators (mechanical → electrical)	70–99%
Electric motor (electrical → mechanical)	50–90%
Gas furnace (chemical → thermal)	70–95%
Wind turbine (mechanical → electrical)	35–50%
Fossil fuel power plant (chemical → thermal → mechanical → electrical)	30–40%
Nuclear power plant (nuclear → thermal → mechanical → electrical)	30–35%
Automobile engine (chemical → thermal → mechanical)	20–30%
Fluorescent lamp (electrical → light)	20%
Incandescent lamp (electrical → light)	5%
Solar cell (light → electrical)	5–28%
Fuel cell (chemical → electrical)	40–60%

Table 4.3 EXAMPLES OF HEAT ENGINES

Vapor or Rankine cycle
Steam engine (electrical power plant, old train locomotive)
Refrigerator, heat pump (using Freon)

Gas cycle
Internal combustion: Otto, Diesel cycles (automobiles, trucks)
External combustion: gas turbine (airplanes, electrical power plant), Stirling cycle



howstuffworks.com

(heat->work)	(work->heat)
steam engine	air conditioners
gasoline engine	dehumidifiers
diesel engine	heat pumps
gas turbine	refrigerators