Physics 115
General Physics II

Session 8

Conduction, convection, radiation
Ideal gas laws

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Lecture Schedule (up to exam 1)

Date	Day	Lect.	Topic	readings in Walker
31-Mar	Mon	1	Introduction, Preview	
1-Apr	Tues	2	Density & Pressure	15.1-15.3
3-Apr	Thurs	3	Static Fluids, Buoyancy	15.4-15.5
4-Apr	Fri	4	Fluid Flow, Bernoulli	15.6-15.8
7-Apr	Mon	5	Viscosity, Flow, Capillaries	15.9
8-Apr	Tues	6	Temperature, expansion	16.1-16.3
10-Apr	Thurs	7	Heat, Conduction	16.4-16.6
11-Apr	Fri	8	Ideal gas	17.1-17.2
14-Apr	Mon	9	Heat, Evaporation	17.4-17.5
15-Apr	Tues	10	Phase change	17.6
17-Apr	Thurs	11	First Law Thermodynamics	18.1-18.3
18-Apr	**Fri**		**EXAM 1 Ch 15,16,17**	

Today

Just joined the class? See course home page
courses.washington.edu/phy115a/
for course info, and slides from previous sessions

Announcements

- Reminder: Bring your clicker every day from now on
- Exam 1 next Friday 4/18, chs. 15, 16, 17 in text
  - All multiple choice questions – some conceptual, some calculation
    - Similar to homework questions and other questions in text
    - 16 questions, average student should finish early
  - Only calculators allowed, no phones, pads, laptops
  - YOU must bring bubble sheet and pencil
  - No special seat assignments
  - Formula page will be included

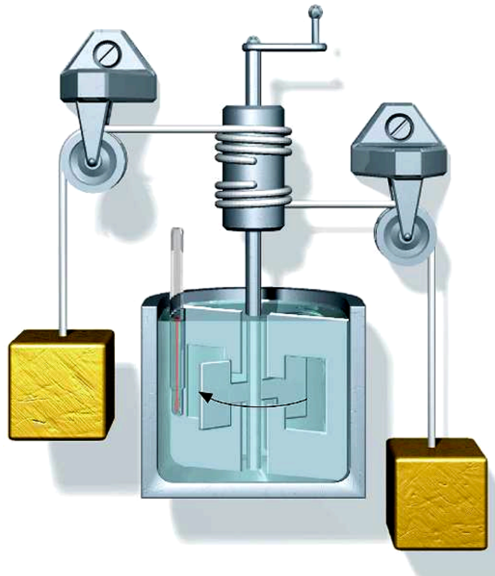
Mechanical equivalent of heat

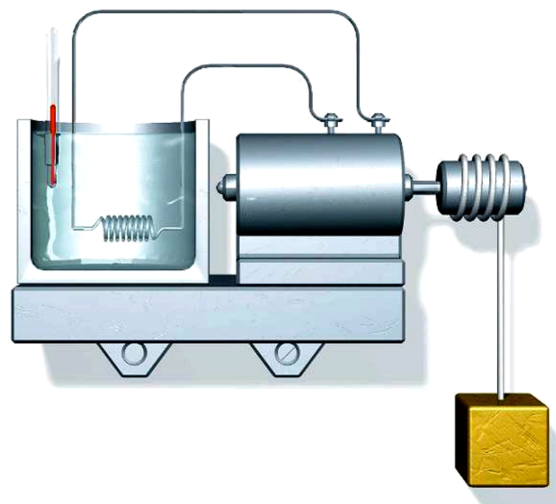
The T of a system can be increased by adding heat, but it can also be increased by doing work on it.

James Joule found (1845) that he could raise the temperature of 1.00 lb of water by 1.00°F by stirring it, using the energy from dropping 772 lb of weights by a distance of 1 ft.

Converting this to modern SI units: Joule found that it takes about 4.186 J of energy to increase the temperature of 1.00 g of water by 1.00°C.

A modern version: dropping weight turns an electrical generator, which runs electric current through a heating coil immersed in water. The work-to-heat conversion would be the same.





Heat and work example: falling water heats up

(a) At Niagara Falls, the water drops 50 m. Assuming that the entire decrease in gravitational potential energy goes into the increase in heat energy, what is the increase in water temperature?

$$mgh = mc\Delta T$$

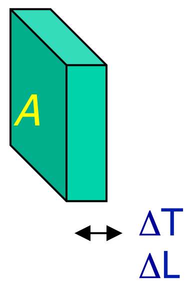
$$\Delta T_{\mathrm{N}} = \frac{gh_{\mathrm{N}}}{c} = \frac{(9.81\ \mathrm{N/kg})(50\ \mathrm{m})}{\left(4.184\ \mathrm{kJ/kg \cdot K}\right)} = 0.12\mathrm{K} = 0.12°\mathrm{C}$$

(b) At Yosemite Falls, the water drops 740 m. What is the water temperature increase there?

$$\Delta T_{\mathrm{Y}} = \frac{gh_{\mathrm{Y}}}{c} = \frac{(9.81\ \mathrm{N/kg})(740\ \mathrm{m})}{\left(4.184\ \mathrm{kJ/kg \cdot K}\right)} = 1.7\mathrm{K} = 1.7°\mathrm{C}$$

Conduction of heat

- Heat *conduction* = transfer of heat through an object by physical contact
- Heat conducted through a slab of material is proportional to:
  - Area of contact (A in m^2)
  - Temperature *difference* from one end to the other (ΔT)
  - *Inversely* prop to distance from one end to the other (L)
  - How long you wait (time t)
  - Properties of the material (its thermal conductance)
  - So: $$Q \propto A \frac{(T_1 - T_2)}{L} t$$



- As usual we can convert proportionality to equality by inserting a constant: $$Q = kA \frac{(T_1 - T_2)}{L} t$$
  - k = material property: thermal conductivity
  - units: (kcal/s)/(m^2)/(°C/m), or equivalent in other unit systems

Substance	Thermal conductivity, $k[W/(m \cdot k)]$
Silver	417
Copper	395
Gold	291
Aluminum	217
Steel, low carbon	66.9
Lead	34.3
Stainless steel—alloy 302	16.3
Ice	1.6
Concrete	1.3
Glass	0.84
Water	0.60
Asbestos	0.25
Wood	0.10
Wool	0.040
Air	0.0234

Conductivity

recall:
4184 J = 1 Cal = 1000 cal

- Metal *feels* cold because it conducts heat away from your hand efficiently
- Notice: water has low heat *conductivity* but big heat *capacity*

Example: 1 m^2 glass window 20°C inside, 0°C outside
What is heat loss rate through plain glass 0.5cm thick?

$\Delta Q=(0.0025)(10^4 cm^2)(20°/0.5)=1000$ cal/s = 4184 J/s = 4kW

- *Double-glazing:* insert a 0.5cm *air* layer between two layers of glass (same as above)...

Try re-calculating the rate of heat loss now...

- Example: Steel rod has A=1 $cm^2 = 10^{-4}$ m^2, d = 1 m, T_1 = 1000 °C, T_2 = 0 °C

For steel, k=50 *W/(m K), c* =400 $J \cdot kg^{-1} \cdot K^{-1}$, density 8000 kg/m^3

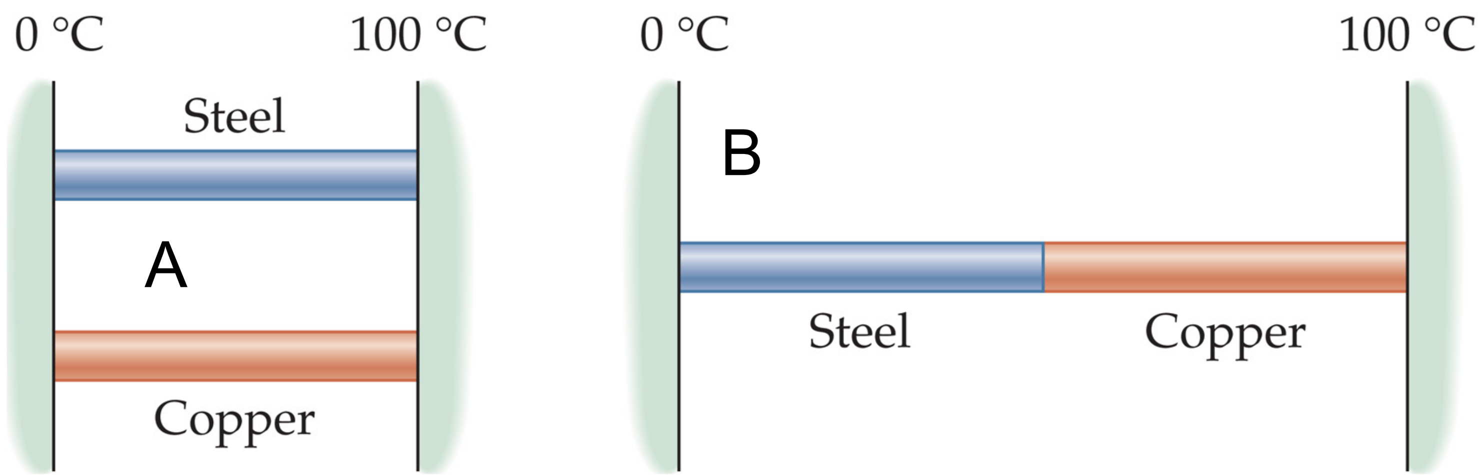
After a long time ("steady state"):

$$Q/\sec = kA\frac{(T_1 - T_2)}{d} = 50\left(\frac{W}{m\ K}\right)\left(10^{-4}\ m^2\right)\frac{1000^\circ}{1m} = 5W$$

Note: size of deg C = 1 K

Conduction: 'parallel' vs 'series' arrangements

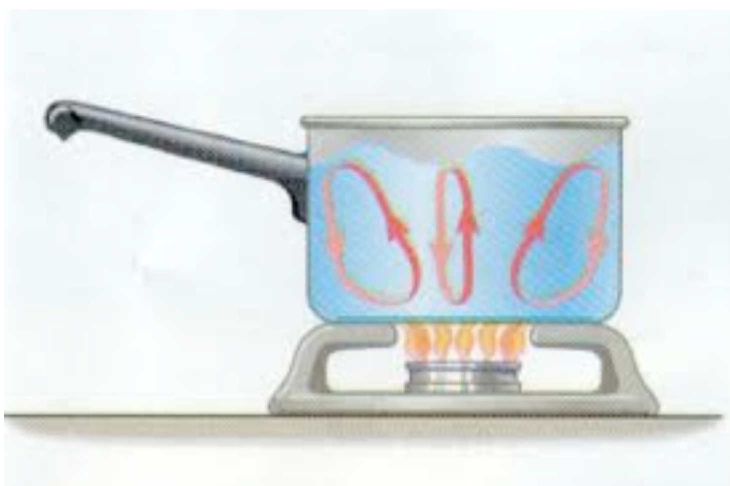
- Two metal rods of different conductivities, same L and area, connect "temperature reservoirs" (big sources of heat that maintain constant temperature despite rods)



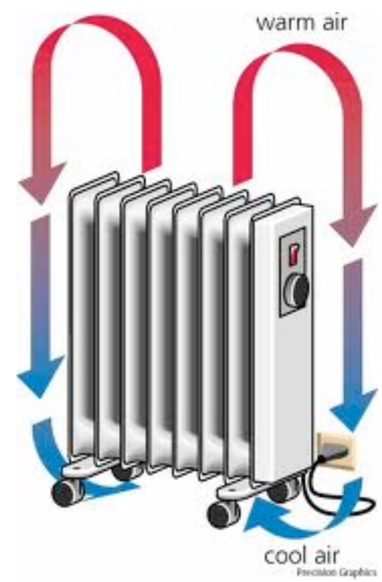
- By analogy to electrical circuits, we call A "parallel" and B "series" connections
- Which arrangement conducts more heat from hot to cold source?
  - Using logic alone we can say it must be A
    - Twice as much area (Q ~ A)
    - Shorter path length (Q ~ 1/L)

Heat transfer: convection

- Convection = heat transfer by bulk motion of material (fluid)
  - Natural convection: density change due to added heat causes fluid to rise and be replaced by cooler (denser) fluid that also will heat and rise: circulation
    - Notice: this requires flow of the fluid
      - Stop the circulation, no convection
  - Forced convection: large volume of fluid is pumped over surface
    - Used to cool electronics, machinery, etc



“radiators” should really be called “convectors”



Heat transfer: radiation

- Radiative heat transfer
  - Emission or absorption of electromagnetic radiation
  - Propagates through vacuum: no material connection needed
- Stefan-Boltzman radiation law:

$$P_{rad} = A\varepsilon\sigma T^4, \quad A = area, \quad \varepsilon = emissivity, \quad \sigma = 5.67\times10^{-8} Wm^{-2}K^{-4}$$

(Stefan-Boltzman constant)

  - If $\varepsilon = 1$, the object is called a blackbody: 100% efficient emission
  - Radiation spectrum peaks at shorter wavelengths for higher T
    - Object with T ~1000K looks red, 3000K looks yellow, 10,000K looks blue
- Generally, absorptivity = emissivity, so absorption has same form, but now T = temperature of environment

Net rate of heat transfer from object at temperature T (in K) is

$$P = P_{rad} - P_{absorbed} = \varepsilon A\sigma\left(T^4 - T_0^4\right), \quad T_0 = \text{environment temp.}$$

Example of radiation heat loss

- Spacecraft far from the Sun has surface area 10 m^2 and emissivity 0.9
  - Electronics on board needs to be kept at or above -40 °C = 233 K
  - Effective temperature of deep space (environment) is 2.75 K
- How much heat per second (= power in watts) does the spacecraft lose due to radiation?

$$P_{rad} = \varepsilon A \sigma \left(T^4 - T_0^4\right), \quad T = 233\ K, \quad T_0 = 2.75\ K$$

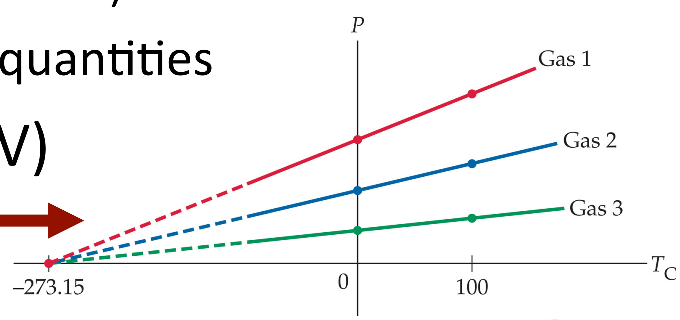
$$P_{rad} = (0.9)\left(10 m^2\right)\left(5.67 \times 10^{-8} W m^{-2} K^{-4}\right)\left(233^4 - 2.75^4\right)$$

$$= 1504\ W$$

SO: If heat generated by its electronics is less than 1504 W, a heater is needed; if larger, additional surface area must be added for cooling

Real and ideal gases

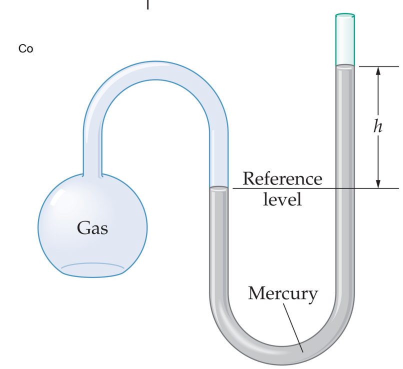
- Real gas: molecules occupy space, interact with each other
- Ideal gas = simple model: no interactions, negligible size
  - BUT: Real gases are close to ideal for many applications
- State of system = set of physical quantities that describe it
  - For ideal gas: mass, volume, pressure, and temperature
    - Mass = Number of molecules N * (mass/molecule)
  - Equation of state = relation between these quantities
- Observed behavior of gases: P vs (N, T, V)
  - P is proportional to T, for V and N fixed
  - P is proportional to N, for V and T fixed
  - P is *inversely* proportional to V, for T and N fixed



$$\therefore \quad P \propto \frac{NT}{V} \rightarrow P = k\frac{NT}{V}, \quad or \quad PV = NkT$$

$$k = \text{Boltzmann's constant} = 1.38 \times 10^{-23} J/K$$

Deep significance: fundamental constant of Nature



Avogadro's number

Counting molecules to get N is difficult, so it is convenient to use Avagadro's number N_A, the number of carbon atoms in exactly 12 g (1 mole) of carbon. 1 mol = {molecular mass, A} grams of gas (For elements, what you see on the Periodic Table is A averaged over isotopes)

N_A = 6.022 x 10^{23} molecules/mole and $N = nN_A$, where n = number of moles of gas

$$PV = nN_A kT = nRT$$

Notice PV = energy: N-m

$$R = N_A k = 8.314 \text{ J/(mol}\cdot\text{K)}$$

$$\boxed{PV = nRT}$$

Ideal Gas Law, in moles
R = "Universal gas constant"
Good approx at low P for real gases

Notice: for real gases,
PV/nT = 8.3J/(mol·K) only at low P