PHYS 1220, Engineering Physics, Chapter 17 – Temperature and Heat

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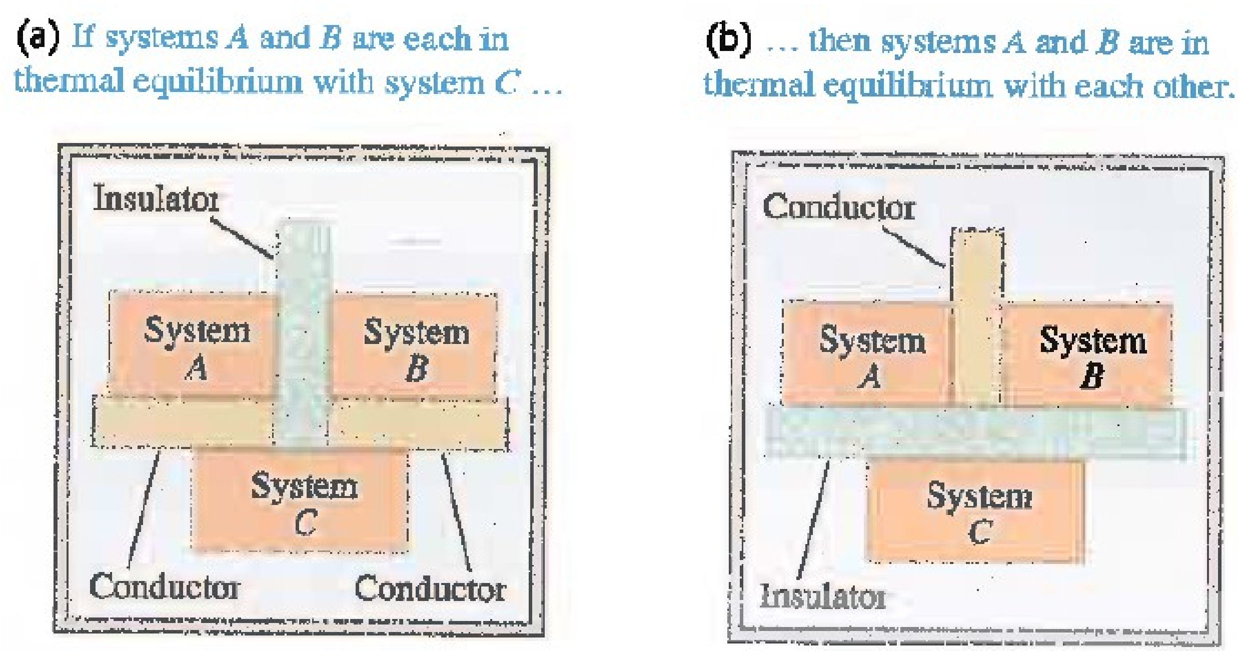
Goal of this chapter is to learn the nature of Temperature and Heat.

- What is Temperature and what is heat?
  - Temperature is a quantitative measurement of hotness/coldness; while Heat is a form of energy that could alter the value of temperature.
  - Thermal equilibrium is a state that two objects reach the same temperature by exchanging heat.

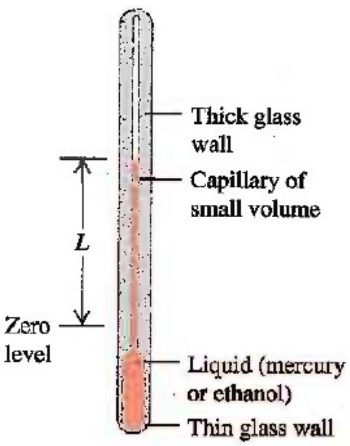
Zeroth law of thermodynamics: If two separated systems/objects are each in thermal equilibrium with a third system/object simultaneously. All three systems/objects are in thermal equilibrium with each other, and thus all three have same temperature.

- Note: Zeroth law of thermodynamics is the basis why thermometer works. Thermometer is, in fact, measuring its own temperature (will discussed later). With Zeroth law, we know that the measured temperature is also the temperature of the object that has thermal equilibrium with the thermometer.

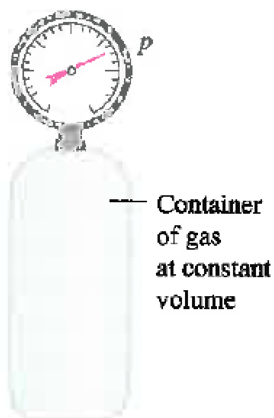


- How temperature is measured?
  - Use anything that has significant reactions/changes upon change of temperature.

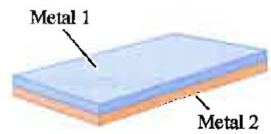
(a) Changes in temperature cause the liquid's volume to change.



(b) Changes in temperature cause the pressure of the gas to change.

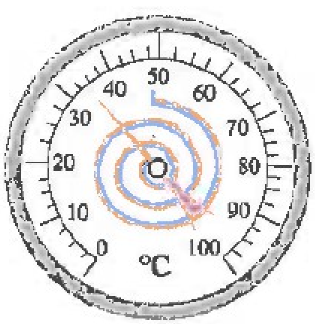


(a) A bimetallic strip

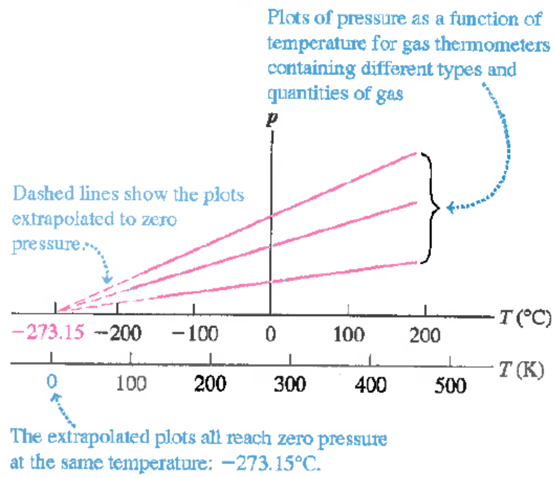


(b) The strip bends when its temperature is raised.

(c) A bimetallic strip used in a thermometer



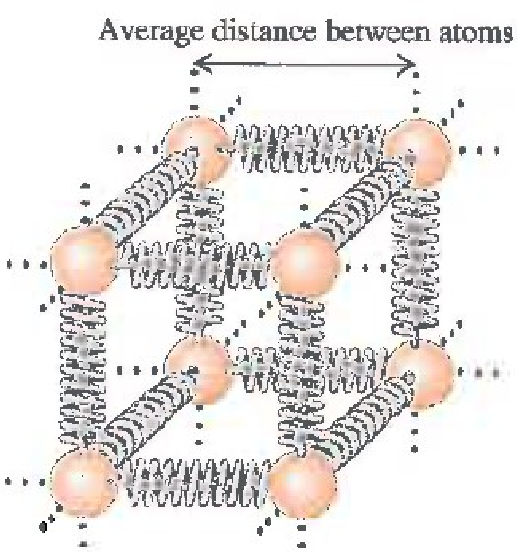
- Typical temperature scales
  - **Fahrenheit, Celsius, and Kelvin**
  - $T_F = \frac{9}{5} T_C + 32$ (or $T_C = \frac{5}{9}(T_F - 32)$)
  - $T_K = T_C + 273.15$
  - In constant volume gas thermometer: $\frac{T_2}{T_1} = \frac{p_2}{p_1}$, where T_1, and T_2 are in the unit of Kelvin. (Will discuss more in Chapter 18)



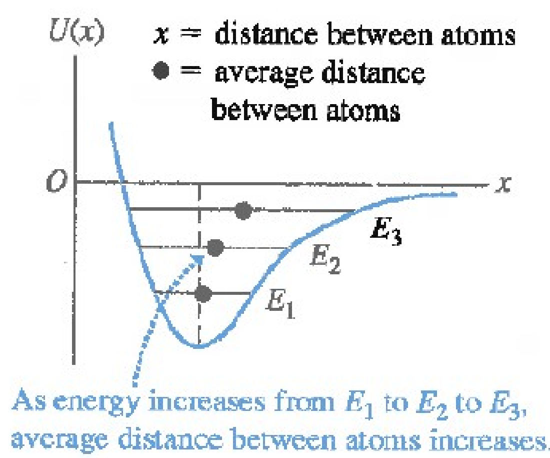
- How to describe thermal expansion of solid materials?

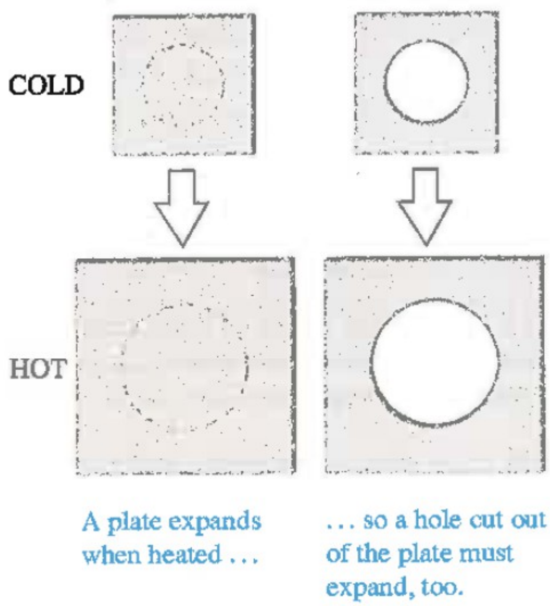
- $\Delta L = \alpha L_0 \Delta T$ (Linear thermal expansion) (similar equation as temperature-dependent resistance or resistivity in metal: $R(T) = R_0[1+\alpha(T-T_0)]$)
- $\Delta V = \beta V_0 \Delta T$ (Volume thermal expansion)
- Note: $\beta = 3\alpha$
- Note #2: Volume of materials as function of temperature typically is not a linear function (does not change proportionally). These equations above are approximation in small temperature range.

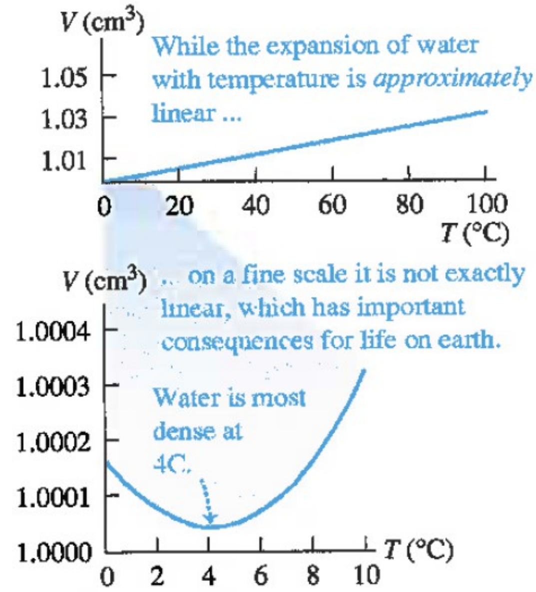
(a) A model of the forces between neighboring atoms in a solid



(b) A graph of the "spring" potential energy $U(x)$

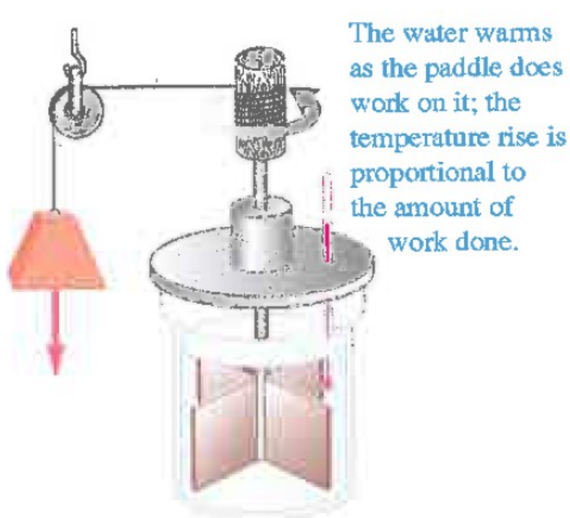




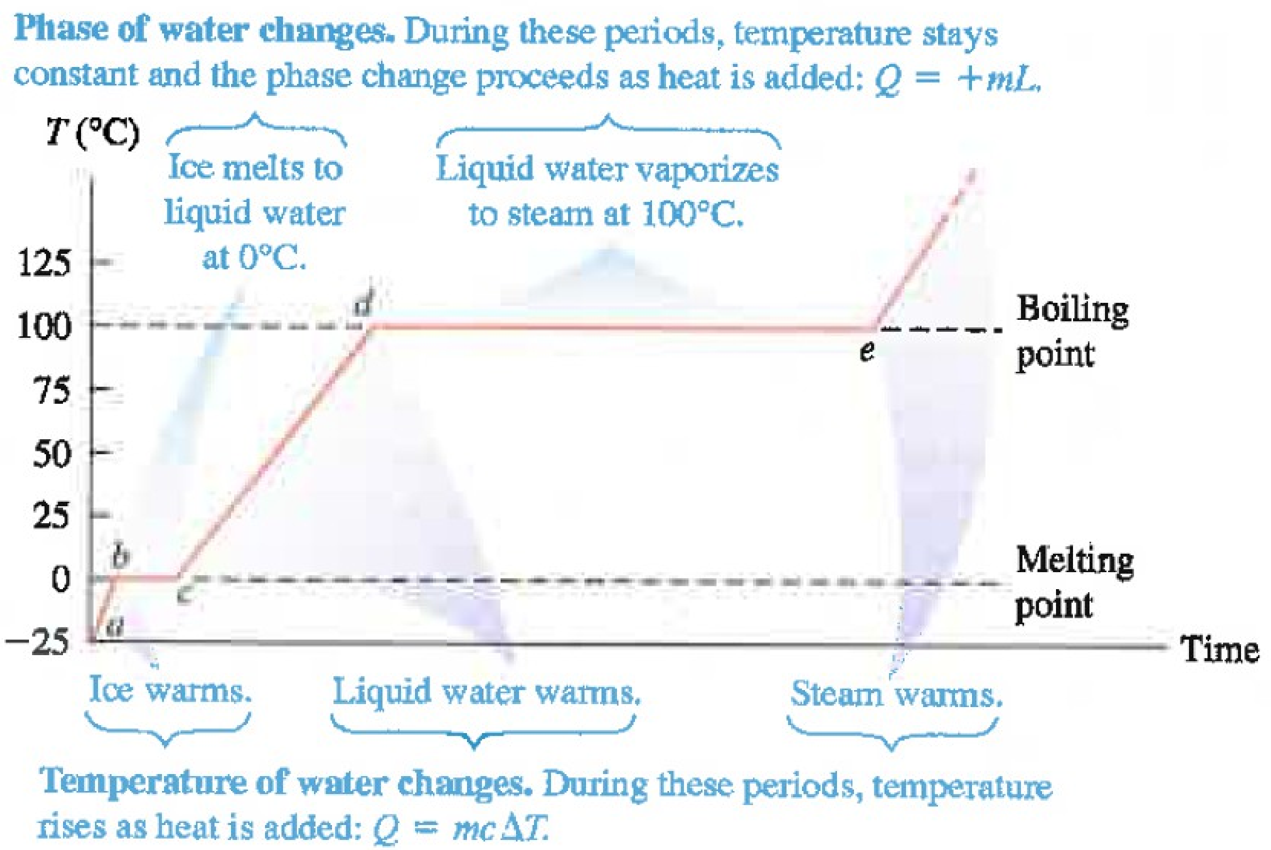


- What is heat? How it is related to temperature? How to calculate?

- Unit: $1\,cal = 4.186\,J$; $1\,kcal = 1000\,cal = 4186\,J$; $1\,Btu = 252\,cal = 1055\,J$
- Specific heat: $c = \frac{1}{m}\frac{dQ}{dT}$ (amount of energy needed to increase a unit temperature of the material with a unit mass) ($\frac{J}{kg\cdot K}$, $\frac{cal}{g\cdot C^o}$, $\frac{Btu}{lb\cdot F^o}$)
- Specific heat is a material-dependent quantity.
- $Q = mc\Delta T$
- $Q = nMc\Delta T = nC\Delta T$ (*n*: number of moles; *M*: molar mass; C: molar heat capacity)
- Note: molar heat capacity, C, is another form of specific heat with different unit. (amount of energy needed to increase a unit temperature of the material with mole of molecules)



- Phase changes
  - We know when boiling water, the water could reach a maximum temperature ~ 100 C^o and start boiling. Even if you keep heating, the temperature is not changing. If the temperature does not increase, where does the heat go to?
  - The energy goes to help materials change phase – phase change.
  - "liquid – vapor"; or "solid – liquid" are two phase changes for H_2O at 1 atm.
  - $Q = mL$ (L: latent heat)
  - $L_{liq-vap} = 2.256\times10^6 J/kg = 539\, cal/g = 970\, Btu/lb$
  - $L_{sol-liq} = 3.34\times10^5 J/kg = 79.6\, cal/g = 143\, Btu/lb$



- How heat transfer?
  - Three major mechanisms: (1) Conduction; (2) Convection; and (3) Radiation

- Conduction:
  - Conduction is based on the heat flow in material (very similar to electron conductivity in current)
  - $H=\frac{dQ}{dt}=kA\frac{T_H-T_L}{L}$ ($I=\frac{V}{R}=\frac{V_H-V_L}{\frac{\rho L}{A}}=\frac{1}{\rho}A\frac{V_H-V_L}{L}$)
  - k in the above equation is called "thermal conductivity"

- Convection:
  - Convection is based on the flow of fluid that carries heat away with it.

- Radiation:
  - Radiation is based on electromagnetic waves that carry energy in or out of the system. Thus, this method requires NO contacts with other object NOR fluid (such as air).
  - $H=Ae\sigma T^4$ (Stefan-Boltzmann law) (A: area of the surface of the object)
  - e: emissivity (describing how easy the radiation could be emitted out of the object. It is ranging from 0 to 1, with 1 as easiest and 0 as hardest)
  - $\sigma=5.670400\times10^{-8}W/m^2\cdot K^4$ (Stefan-Boltzmann constant)
  - Note: the object could emit radiation, and also absorb radiation. For absorption, use same equation (Stefan-Boltzmann law), but change temperature to surrounding environment temperature, T_s.

Math Preview for Chapter 18:
- rms (root-mean-square)
- Integrations with a Gaussian function

Questions to think about for Chapter 18:
- What does it mean as temperature and heat for atoms or molecules in gas or solid materials?