PHYS 1220, Engineering Physics, Chapter 18 – Thermal Properties of Matter

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Goal of this chapter is to learn the thermal properties of gases and how to read phase diagram.

- I have 2.5 dozens of identical coins with total weight of 300 g. How much weight does one dozen of coins have? How much weight does one coin have?

- I have 2.5 moles of identical molecules with total weight of 300 g. How much weight does one mole of molecules have? How much weight does one molecule have?

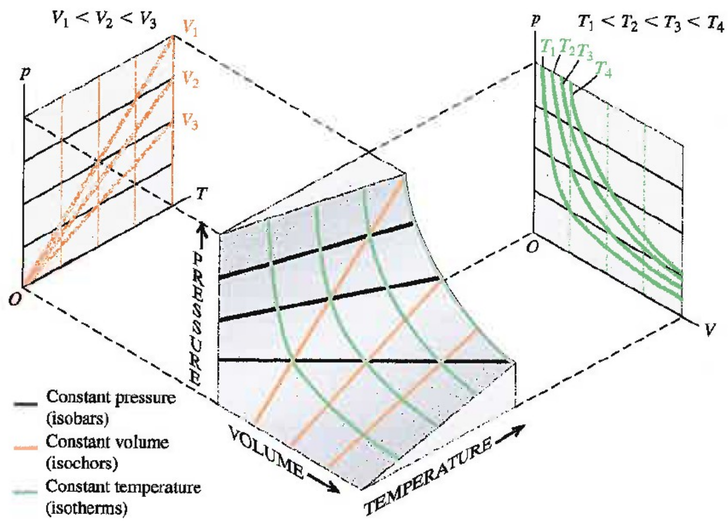
- Confusing Notations (don't be confused):
  - *N: number of molecules*
  - *n*: number of moles
  - N_A: Avogadro's number: 6.02×10^{23} . (Note: The concept of Avogadro's number (and mole) is very similar to "dozen". They all represent one particular number (dozen = 12))
  - *M*: molar mass (how much mass per mole)
  - *m*: mass of ONE molecule
  - m_{total}: total mass
  - *p*: pressure
  - *P*: momentum

- Molar mass and total mass
  - $M = N_A m$

- $m_{total} = n\,M$

- Equations of state:

- Ideal gas: $pV = nRT$
- $\rho = \frac{pM}{RT}$
- $R = 8.314\, J/mol \cdot K$; $R = 0.08206 \frac{L \cdot atm}{mol \cdot K}$
- Non-ideal gas (van der Waals): $(p + \frac{an^2}{V^2})(V - nb) = nRT$



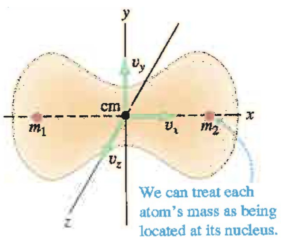
- Kinetic-molecular model of an ideal gas (link between temperature and molecule kinetic energy) (link between microscopic molecules and macroscopic measurable properties)

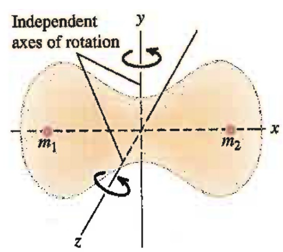
- $K_{tr} = \frac{3}{2} nRT$ (K_{tr} : total kinetic energy due to translational motion, sum of all molecules)
- $\frac{1}{2} m (v^2)_{av} = \frac{3}{2} kT$ (average kinetic energy due to translational motion of a single molecule)
- $k = \frac{R}{N_A} = 1.381 \times 10^{-23} J/molecule \cdot K$ (**Boltzmann constant**)
- $v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$

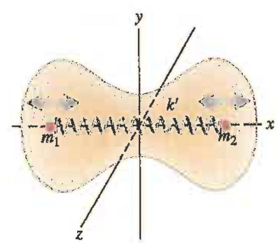
- Heat Capacity

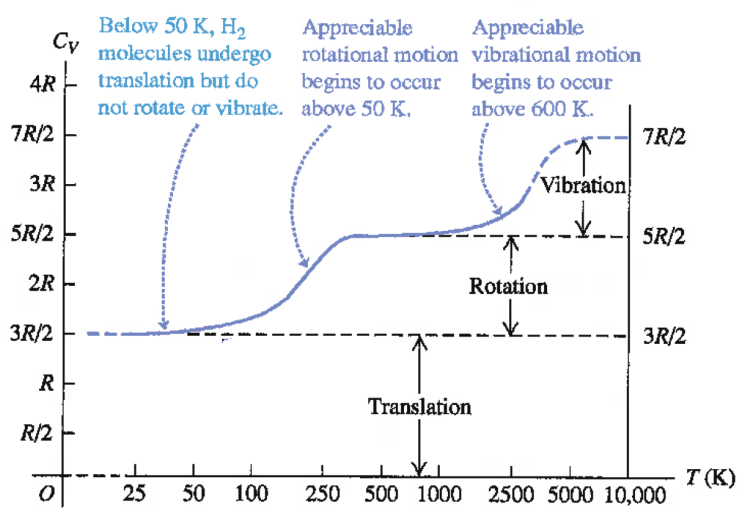
- $dK_{tr} = \frac{3}{2} nR\,dT$; $dQ = n\,C_V\,dT$

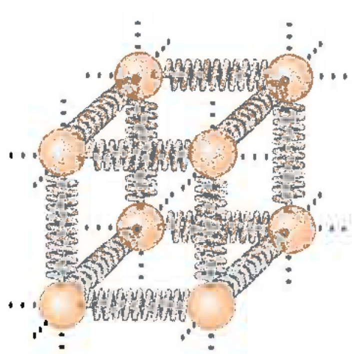
- $C_V = \frac{3}{2}R$ for ideal gas of point molecule ($C_V = \frac{dof}{2}R$; dof: degrees of freedom) (each degree of freedom could have $\frac{1}{2}kT$ energy per atom)
- $C_V = \frac{5}{2}R$ for diatomic gas, including 2 rotational degrees of freedom and 3 translational degrees of freedom
- $C_V = \frac{6}{2}R = 3R$ for ideal monatomic solid, each atom has 3 translational degrees of freedom (kinetic energy), and 3 vibrational degree of freedom (potential energy)
- $C_V = \frac{7}{2}R$ for diatomic gas, including 2 rotational degrees of freedom, 3 translational degrees of freedom, and

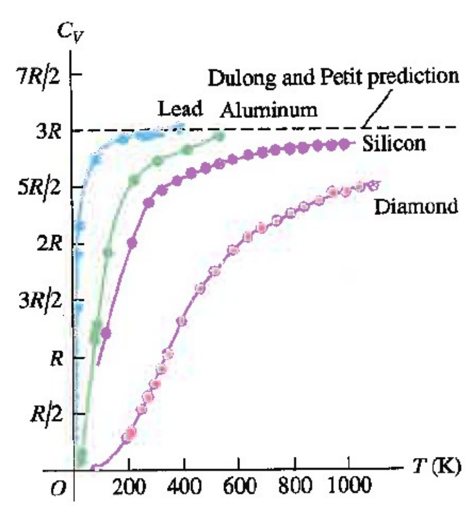




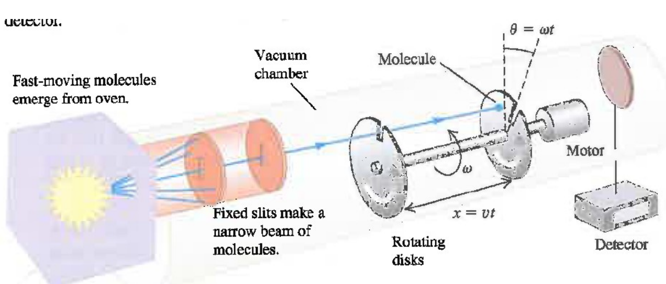


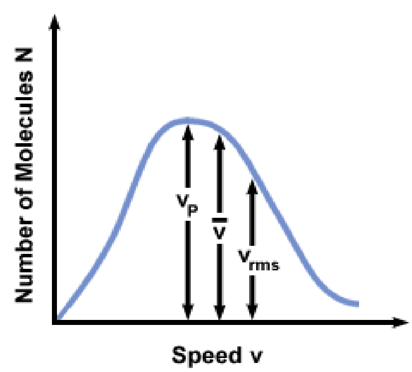




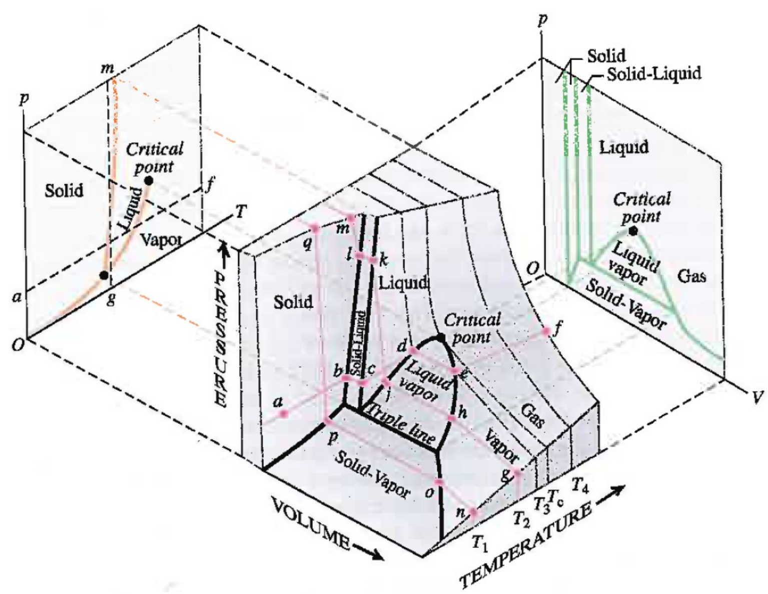


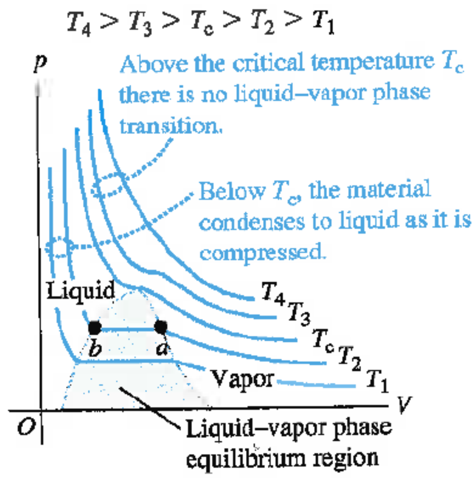
- Molecular speed distribution
  - Basic statistics:
    - Distribution function (similar to probability function)
    - $f(v)$ means "the probability of finding the particle with speed v"
    - $\int_0^\infty f(v)\,dv = 1$ (sum of all probability equal to 1)
    - $v_{av} = \int_0^\infty v f(v)\,dv$
    - $(v^2)_{av} = \int_0^\infty v^2 f(v)\,dv$
  - Maxwell-Boltzmann distribution function (for classical particles)
    - $f(v) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2\mathrm{kT}}$ (distribution function)
    - $v_{mp} = \sqrt{\frac{2\mathrm{kT}}{m}}$ (most probable speed)
    - $v_{av} = \sqrt{\frac{8\mathrm{kT}}{\pi m}}$ (average speed)
    - $v_{rms} = \sqrt{\frac{3\mathrm{kT}}{m}}$ (root-mean-square speed)

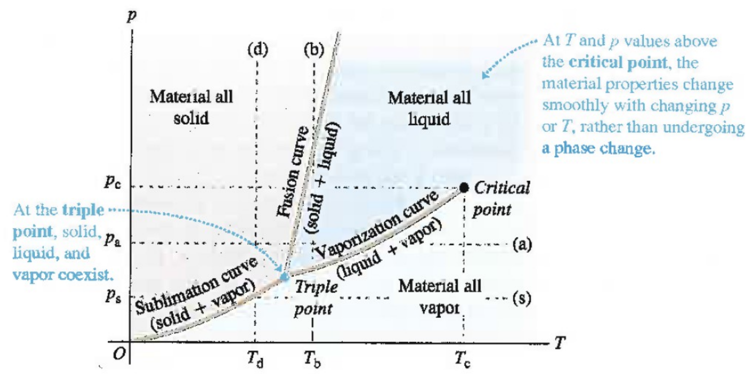




- Phase diagram of matters







Math Preview for Chapter 19:

- integration

Questions to think about for Chapter 19:

- Heat is one kind of energy, so is work. If a system gains heat and perform work to the surrounding of the system, how would the temperature of the system change? Increase or decrease?