EPFL

ETA-Lab
Energy Transport Advances

ME-251: Thermodynamics and energetics I
Thermodynamic Properties II

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Photo Credit: Trougnouf

Last Time

- Enthalpy
- Specific heat
- Evaluating thermodynamic properties with CoolProp

ILOs Today

- Estimate thermodynamic properties in special cases
  - Incompressible substance
  - Ideal gas

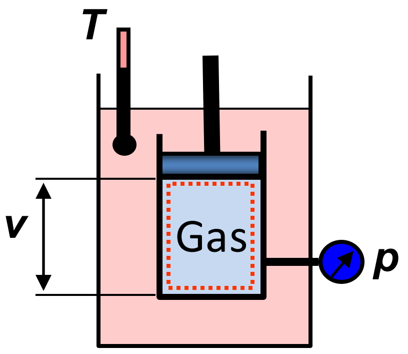
○ Reading: Moran 3.10-3.15

Incompressible Substance

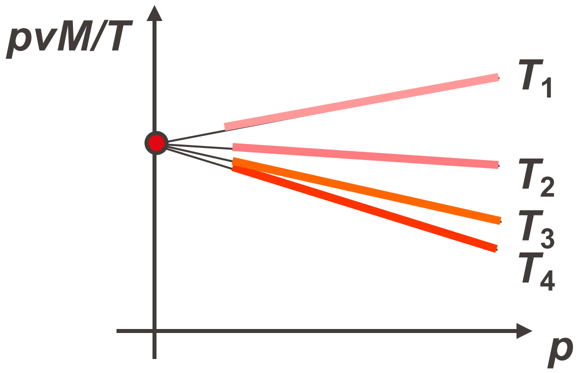
- Liquids and solids are often modeled as incompressible

In general *u* is a function of *v and T*

Gases



- Consider gas confined in a piston-cylinder assembly and held at a constant temperature.
- Gas pressure is varied through piston movement
- At a constant temperature, the pressure and specific volume are measured.



Universal Gas Constant

- $\tilde{R} = 8.314$ J/K/mol

- $\tilde{R}$ is the same for different gases, the specific gas constant R is different for different gases

- $\tilde{R} = k_B N_A$
  - The Boltzmann constant $k_B = 1.38 \times 10^{-23}$ [J/K], converts temperature scale to thermal energy scale for individual particles
  - The Avogadro constant $N_A = 6.022 \times 10^{23}$ [1/mol], historically defined to make one mole of hydrogen atoms weigh 1 gram

Compressibility Factor

Viral Equations of State

$$Z = 1 + \frac{B(T)}{\tilde{v}} + \frac{C(T)}{\tilde{v}^2} + \frac{D(T)}{\tilde{v}^3} + \cdots$$

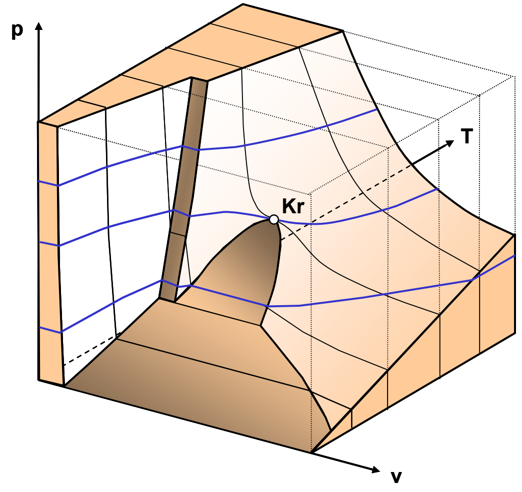
$$Z = 1 + \hat{B}(T)p + \hat{C}(T)p^2 + \hat{D}(T)p^3 + \cdots$$

Viral coefficients B, C, D (or $\hat{B}, \hat{C}, \hat{D}$) account for intermolecular interactions and can be derived from statistical mechanics

Ideal Gas Model

- Ideal gas model:
  - No intermolecular interactions (other than elastic collision)
  - Volume of molecules ignored

- When we approximate real gases as ideal gas



Ideal Gas Thermodynamic Properties

Ideal Gas Polytropic Processes

- A process where $pv^n = \text{const}$
  - Isobaric process: $p = \text{const}$
  - Isothermal process: $pv = RT = \text{const}$
  - Isochoric processes: $v = \text{const}$
  - Isentropic process (not covered yet): $pv^k = \text{const}$

Ideal Gas Polytropic Processes

- Compression/expansion work (intensive form)

$$w = \int_1^2 p dv = \begin{cases} p_1 v_1 \ln\left(\frac{v_2}{v_1}\right), n = 1 \\ \frac{p_2 v_2 - p_1 v_1}{1-n}, n \neq 1 \end{cases}$$

- Applying ideal gas law

$$w = \int_1^2 p dv = \begin{cases} RT \ln\left(\frac{v_2}{v_1}\right), n = 1, \text{isothermal} \\ \frac{R(T_2 - T_1)}{1-n}, n \neq 1 \end{cases}$$

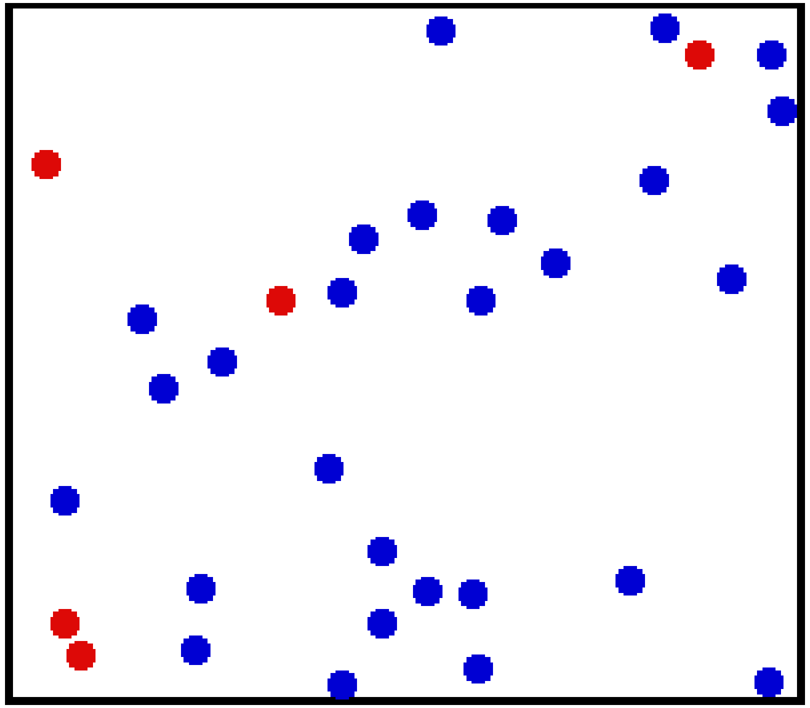
Perfect Gas

- Special case of ideal gas (also called calorically perfect)
  - Like an ideal gas and what’s more, the specific heats are approximated as **independent of temperature**

Monoatomic
Diatomic
Polyatomic

Crash Course on Kinetic Theory of Gases

- Consider gas as **a large number of randomly moving particles** that collide with one another every now and then
- Collisions are elastic: **kinetic energy is conserved** before and after
- Between collisions, particles are not affected by any force field



Credit: A. Greg

Temperature Revisited

- The kinetic theory defines temperature by considering the average kinetic energy of a particle in a system

- The average translational kinetic energy $e_{kt} = \frac{3}{2}kT$

Specific Heat From Kinetic Theory

- If an ideal gas system only contains monatomic molecules (Ar, He,..), one only needs to consider translational kinetic energy

$$U = \frac{3}{2} N_{sys} kT$$

- For monatomic ideal gases

$$c_v = \frac{1}{m_{sys}} \frac{dU}{dT} = \frac{3}{2} \frac{N_{sys}}{Mn} \frac{\tilde{R}}{N_A} = \frac{3}{2} R$$

- For diatomic and polyatomic molecules, internal energy can also come from rotation and vibration, still proportional to temperature.

Gas Model Summary